ARMY RESEARCH LABORATORY

Methodology for the Analysis of Obscurant Attenuation Effects on Seeker Target Acquisition Performance Using Modeling and Simulation

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ARL-TR-1608

AUGUST 1998

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ERRATA SHEET

re: ARL-TR-1608, "Methodology for the Analysis of Obscurant Attenuation Effects on Seeker Target Acquisition Performance Using Modeling and Simulation," by Joseph A. Andrese of the Survivability/Lethality Analysis Directorate, ARL

The following pen-and-ink change should be made on page 19 in the eleventh line from the bottom, under the heading "3.3 Optical Depth":

Equation (3)

should be changed to read

Equation (4)

Abstract

A methodology was developed which uses modeling and simulation to obtain data for analyzing smoke/obscurant attenuation effects on sensor/seeker target acquisition performance. A computer routine written in Formula Translator (FORTRAN) 77 code integrates smoke/obscurant clouds generated by the combined obscuration model for battlefield-induced contaminants (COMBIC) with seeker performance from a system hardware-in-the-loop simulation. The methodology can be applied to other system models and simulations. The computer routine calculates the azimuth and elevation angular position of the line of sight (LOS) between the seeker and an incoming threat aircraft, determines the transmission along the LOS between the seeker and aircraft, and obtains the smoke/obscurant-attenuated seeker target acquisition range from the system simulation. Output consists of seeker target acquisition range contours as functions of target down-range and off-range positions and smoke/obscurant conditions. Seeker performance analysis consists of the extent of degradation of maximum acquisition range, statistical comparisons of the percent frontal area target acquisition coverage figure of merit as a function of smoke/obscurant conditions, and the ability to meet maximum acquisition range requirements at specified optical depths. The Bradley Linebacker Stinger target acquisition performance in battlefield smoke/obscurants is included as an example of the methodology usage.

ACKNOWLEDGMENTS

The author gratefully acknowledges the excellent technical contributions and support in development of the technique described in this report from

Ms. Scarlett Ayres, Mr. Raul Gonzalez, Ms. Jill Thompson, and Mr. Young Yee of the Survivability/Lethality Analysis Directorate (SLAD) of the U.S. Army Research Laboratory (ARL), White Sands Missile Range (WSMR), New Mexico, for expertise in the use of the combined obscuration model for battlefield-induced contaminants (COMBIC) and the production of smoke grenades and vehicular dust obscurants data.

Mr. Gary H. Johnson, SLAD of ARL at WSMR for Stinger-reprogrammable microprocessor (RMP) hardware-in-the-loop simulation expertise, the development and application of an innovative techniques to represent obscurant attenuation effects in the simulation, and the production of seeker target acquisition data.

Mr. Walter G. Klimek, SLAD of ARL, for technical review and expertise in the smoke/obscurants technical area.

In addition, the author would like to express appreciation to Nancy J. Nicholas, Technical Publications Editor, Chief of Staff Directorate, ARL, Aberdeen Proving Ground, for providing excellent editorial support.

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PREFACE

The work described in this report was funded by the U.S. Army Research Laboratory, Survivability/Lethality Analysis Directorate (SLAD), and the U.S. Army Stinger Product Office, Redstone Arsenal, Alabama. This task was accomplished to support the U.S. Army Operational Evaluation Command (OEC) during the evaluation of the Bradley Linebacker system for the Milestone (MS) IIIb full production decision. Analysis results were provided as input to answer obscurants-related survivability and performance issues in the system evaluation report. The Bradley Linebacker is equipped with the Stinger-reprogrammable microprocessor (RMP) missile and is required to move with and to protect the Abrams main battle tank and the Bradley fighting vehicle against aircraft threats. The ability of the seeker to perform in self-defensive smoke and vehicular dust was considered important to the survivability of the vehicles. A literature search of applicable system reports showed that no previous data existed for the Stinger-RMP seeker performance in obscurants. A methodology was developed to use modeling and simulation to obtain data for analysis. A computer routine written in FORTRAN 77 code was designed to integrate the two sources of data, to calculate the angular line of sight (LOS) between the seeker and the attacking aircraft, and to determine the obscurant-attenuated seeker target acquisition range. The technique that was developed for the Stinger-RMP seeker is applicable to the analysis of obscurants attenuation effects on other sensor/seeker systems, provided a similar system model or simulation is available and has gone through verification, validation, and accreditation (VV&A) procedures.

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EXECUTIVE SUMMARY

Smoke and obscurants are combat multipliers and interfere with weapon systems performance. Man-made smoke combines with natural obscurants to defeat or degrade signals in all areas of the electromagnetic spectrum. Obscurants include man-made smoke and natural obscurants. Degradation of sensor performance occurs through signal attenuation and radiance defeat mechanisms. The analysis methodology described in this report is limited to the measures that show only the attenuation effects on seeker performance.

Obscurant effects on seeker performance analysis results were needed to answer obscurants-related survivability and performance issues for the evaluation of the Bradley Linebacker system. No previous data existed to assess battlefield obscurant effects on the Stinger-reprogrammable microprocessor (RMP) seeker target acquisition performance. The Bradley Linebacker system was being procured under a rapid, low budget acquisition program, and field tests were not possible. Existing models and simulations that had undergone verification, validation, and accreditation (VV&A) procedures were selected as the sources for data. The approved combined obscuration model for battlefield-induced contaminants (COMBIC) and the Stinger-RMP hardware-in-the-loop (HWIL) simulation, which had already gone through VV&A were identified as data sources. Before COMBIC and the HWIL simulation were accepted for evaluation purposes, the U.S. Army Materiel Systems Analysis Activity (AMSAA) and the U.S. Army Operational Test and Evaluation Command (OPTEC) coordinated and agreed on their use. A computer routine was developed to perform target position calculations, to integrate the two sources of data, and to provide seeker performance results.

The Bradley Linebacker main armament consists of four Stinger missiles in the standard vehicle-mounted launcher (SVML) and a 25-mm automatic cannon. The Stinger-RMP is an improved version of the basic Stinger missile using a two-color (ultraviolet [UV] and infrared [IR]) seeker. The Linebacker operates in the forward area of the battlefield, which contains heavy amounts of offensive and defensive military smoke, thermal clutter from burning vehicles and petroleum fires, and large concentrations of vehicular and artillery-generated dust. Sensor performance is reduced during degraded atmospheric conditions. Since the Bradley Linebacker moves with the Abrams main battle tank and the Bradley fighting vehicle, the main sources of obscurant threats were considered to be from self-defensive grenades and vehicular dust from the tracked vehicles. The smoke was from the rapid obscuration system (ROS) brass-filled M76 IR and L8A1 red phosphorus (RP) self-defensive grenades, and the vehicular dust was from five Bradley Linebacker vehicles traveling in convoy mode.

Sophisticated modern weaponry, such as the Bradley Linebacker, uses a myriad of electro-optical sensing devices for target detection and acquisition, which are limited by the battlefield environment. Obscurants used on the battlefield can be produced by combustion of materials such as phosphorus, condensation of vapor such as diesel or fog oil, or dissemination of millimeter wave fibers. Dust produced by artillery and moving vehicles is an unavoidable by-product of the battlefield. Self-defensive smoke can protect U.S. forces from target acquisition by the enemy but can be a double edged sword by rendering main weapons ineffective and thereby decreasing survivability. Most battlefield obscurants attenuate radiant energy used by "smart" weapons to acquire and lock onto the target. Obscurant attenuation effects degrade sensor/seeker target acquisition performance. Field testing of each new weapon system in the appropriate battlefield environments would be ideal but has been found to be both impractical and uneconomical in certain circumstances. Analysis of weapon seeker performance in the presence of obscurants, using approved computer models and simulations, provides a timely, comprehensive, and cost-effective method to assess electro-optical seeker performance in degraded atmospheric conditions that can be expected on the battlefield.

METHODOLOGY FOR THE ANALYSIS OF OBSCURANT ATTENUATION EFFECTS ON SEEKER TARGET ACQUISITION PERFORMANCE USING MODELING AND SIMULATION

1. INTRODUCTION

1.1 Objective

To describe a methodology for analyzing obscurant attenuation effects on sensor/seeker target acquisition performance using modeling and simulation data.

1.2 Background

1.2.1 *Smoke/Obscurants Effects*

Smoke and obscurants are combat multipliers and interfere with weapon systems. Man-made smoke combines with natural obscurants to defeat or degrade signals in all areas of the electro-magnetic spectrum. Obscurants include man-made smoke and natural obscurants. Energy is either emitted by a target and received by a sensor (passive sensing) or transmitted and received by the sensor (active sensing). Obscurants use two basic principles to remove electromagnetic energy from the path of the target to sensor: scattering and absorption. The combination of scattering and absorption is attenuation. Degradation of sensor performance occurs through signal attenuation and radiance defeat mechanisms. The methodology described in this report is limited to the analysis of obscurant attenuation effects only. The important factors that affect attenuation levels are the wavelength of the signal, the amount and type of obscurant in the line of sight (LOS) between the observer and the target, and the path length along the LOS through the obscurant cloud. As the radiated energy is absorbed by the obscurant, the reception range of the seeker decreases. The efficiency of smoke particles in attenuating signal radiation is quantified by the mass extinction coefficient, (units in m^2/gram), which is wavelength dependent. Mass extinction coefficients for obscurant are measured in chambers by standard test processes. Spectral extinction is measured by disseminating a known concentration, C, of the obscurant in a standard chamber. The mass extinction coefficient is calculated by solving the transmittance equation for $\alpha(\lambda)$ as follows:

$$\alpha(\lambda) = -\,1/CL \ln [\,(I(\lambda) / Io(\lambda)\,] \quad (1)$$

in which

C is the known concentration of the obscurant in the chamber, L is the known path length in the chamber, I (λ) = measured spectral (wavelength dependent) intensity with obscurants in the chamber, and Io (λ) = measured spectral (wavelength dependent) intensity with no obscurant in the chamber.

In a field environment, a measure of signal attenuation through obscurants is transmission or transmittance. Transmission is a measure of the amount of electromagnetic energy that passes through the obscurants' aerosol and is a function of the mass extinction coefficient and the amount of obscurant in the path length. Transmission is the ratio of the energy received at the seeker to the energy emitted by the target and is calculated using the Beer-Bouguer Transmittance Law as follows:

$$T = I(\lambda) / Io(\lambda) = e^{-\alpha CL} \tag{2}$$

in which

T = transmission or transmittance, percent or decimal, unitless; I (λ) = energy received by the seeker; Io (λ) = energy emitted or reflected by the target; α = mass extinction coefficient (from chamber test) of the obscurant, m^2/gm; CL = the concentration-path length through the obscurants' cloud.

1.2.2 *Need for Methodology Development*

An analysis of obscurant effects on seeker performance was needed to answer obscurants-related survivability and performance issues for the evaluation of the Bradley Linebacker system. No previous data existed to assess battlefield obscurant effects on the Stinger-RMP seeker target acquisition performance. The Bradley Linebacker system was being procured under a rapid, low budget acquisition program, and field tests were not possible. Because of time constraints, models and simulations previously approved and subjected to verification, validation, and accreditation (VV&A) were used. Validation is the process of determining the extent to which a model or simulation is an accurate representation of the real world from the perspective of the intended use(s) of the model or simulation. Verification is the process of determining that a model or simulation implementation accurately represents the developer's conceptual description and specification. Verification also evaluates the extent to which the model or simulation has been developed using sound and established software engineering techniques. Accreditation is the official certification that a model or simulation is acceptable for use for a specific purpose. The approved combined obscuration model for battlefield-induced contaminants (COMBIC) and the Stinger-RMP hardware-in-the-loop (HWIL) simulation, which had already gone through VV&A, were identified as data sources for the analysis effort. Before COMBIC and the HWIL simulation were accepted for evaluation purposes, the U.S. Army Materiel Systems Analysis Activity (AMSAA) and the U.S. Army Operational Test and Evaluation Command (OPTEC) coordinated and agreed on their use. A computer routine was developed to perform target position calculations, to integrate the two sources of data, and to provide seeker performance results. Results of the analysis were documented in a report **[1]** and provided to AMSAA and OPTEC for their evaluation reports.

1.2.3 *Bradley Linebacker-Stinger Seeker Example Study*

The Bradley Linebacker, shown in Figure 1, is an upgrade from the Bradley Stinger fighting vehicle (BSFV) man-portable air defense system (MANPADS) under armor (BSFV-MUA), which provided a limited interim capability to handle aircraft threats to the armored vehicles traveling in the forward area of the battlefield.

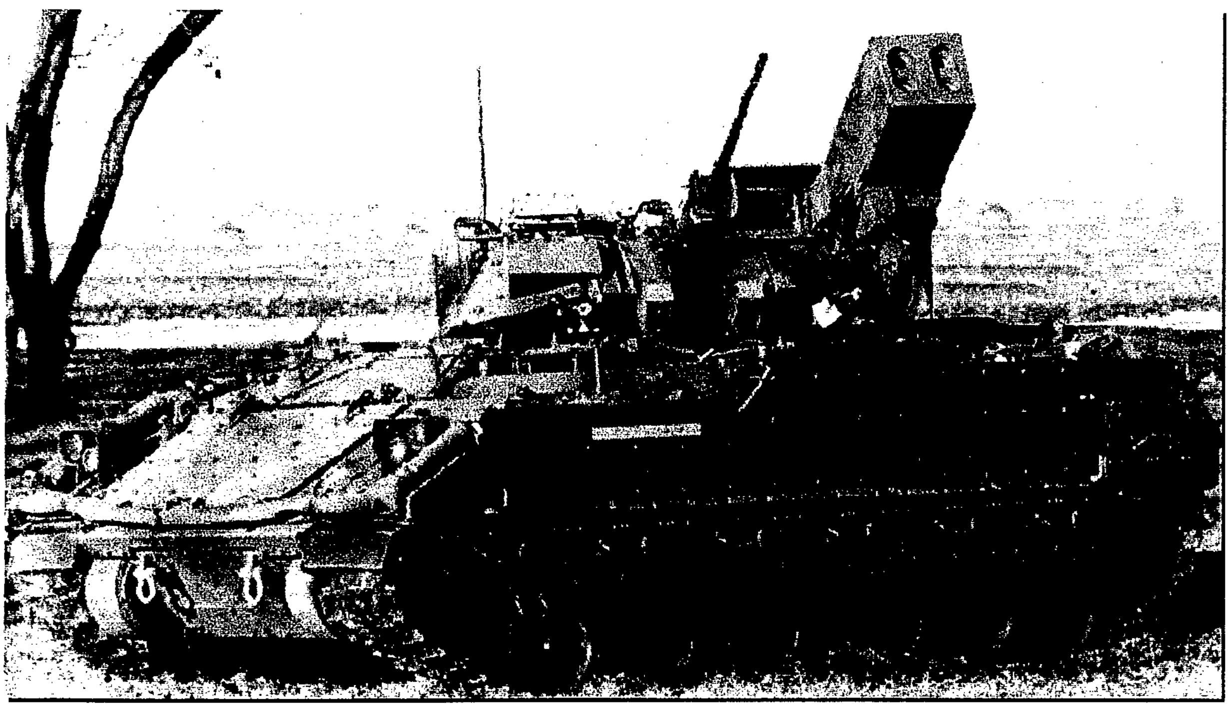

Figure 1. Bradley Linebacker System With Stinger Missiles.

The Linebacker main armament consists of four Stinger missiles in the standard vehicle-mounted launcher (SVML) and a 25-mm automatic cannon. The Stinger-RMP is an improved version of the basic Stinger missile using a two-color (ultraviolet [UV] and infrared [IR]) seeker. The Linebacker operates in the forward area of the battlefield which contains heavy amounts of offensive and defensive military smoke, thermal clutter from burning vehicles and petroleum fires, and large concentrations of vehicular and artillery-generated dust. Sensor performance is reduced during degraded atmospheric conditions. Since the Bradley Linebacker moves with the Abrams main battle tank and the Bradley fighting vehicle, the main sources of obscurant threats were considered to be from self-defensive grenades and vehicular dust from the tracked vehicles. The smoke was from the rapid obscuration system (ROS) brass-filled M76 IR and L8A1 red phosphorus (RP) self-defensive grenades, and the vehicular dust was from five Bradley Linebacker vehicles traveling in convoy mode.

2. METHODOLOGY

2.1 Technical Approach, Limitations, and Assumptions

2.1.1 *Technical Approach*

The methodology uses COMBIC for obscurant data and modeling or simulation for sensor/seeker performance data. A computer routine integrates the attenuation effects of the obscurant clouds generated by COMBIC with the seeker model or simulation. Obscurant clouds are generated for various wind directions and meteorological conditions. The computer routine uses Formula Translator (FORTRAN) 77 code to coordinate the COMBIC and the seeker performance simulation interactions, calculate threat aircraft position information, obtain signal transmission along the LOS in the specified spectral bands, and provide attenuated seeker target acquisition range. Output consists of seeker target acquisition range boundaries as functions of target down-range and off-range positions and obscurant conditions.

2.1.2 *Limitations and Assumptions*

Some assumptions are made in using COMBIC for obscurant data and using seeker models and simulations for system performance data.

The use of COMBIC involves two limitations. The first is that attenuation is the major contributing degradation mechanism. Radiant effects and the effects of multiple scattering and path radiance are not presently addressed by using COMBIC. Future improvements in the COMBIC model are planned to include the combined effects from obscurants, other aerosols, and false target or induced clutter. The second limitation of COMBIC is that Gaussian plume models are treated as representative of the conditions encountered. This limitation is acceptable for studies involving seeker target acquisition only. The signal-attenuation methods described in this report that were used in the HWIL simulation were considered reasonable representations of obscurant results. Attenuation in this analysis was selected to be the point at which the simulated acquisition did not occur because of loss of signal. Attenuation considers only absorption and single scattering (where the first scatter is loss of energy from the path).

An assumption with the use of the HWIL simulation is that targets are always acquired in clear air under the same meteorological, range, and target conditions used in the obscurant scenarios. For example, if the simulation shows a non-acquisition in obscurants at a selected range under the specified meteorological conditions, then the seeker would acquire the target under the same meteorological conditions in clear air.

In all of the obscurant grenade simulations, a given condition is that the grenades are not dispensed until the target reaches the specified input down-range position. In the vehicular dust simulations, computations of the dust cloud were limited to 20-second intervals because dust cloud concentrations did not reach sufficient levels in 1-second intervals to realistically calculate attenuation effects, as occur for grenade smoke cloud concentrations. In 20-second intervals, the vehicular dust cloud concentration reaches computationally significant values.

The meteorological conditions used as inputs to COMBIC were selected to represent a given set of initial representative atmospheric conditions. Wind direction with respect to the seeker position was examined in five orientations.

2.2 Modeling, Simulation, and Computer Routine

2.2.1 *Obscurants Model*

COMBIC was developed and evaluated by the former U.S. Army Atmospheric Sciences Laboratory (now the U.S. Army Research Laboratory [ARL] Information Science and Technology Directorate, Battlefield Environment Division). COMBIC is described in detail in a report **[2]** and has been evaluated and the results presented at numerous Electro-Optical Systems Atmospheric Effects Library (EOSAEL) conferences, smoke symposiums, and in technical reports. A letter **[3]** signed by the Chief of ARL's Battlefield Environment Division qualifies COMBIC validity.

COMBIC predicts time and spatial variations in concentration and transmission through airborne obscurants that include dust raised by high explosive (HE) munitions and vehicular motion; screening smoke from RP, white phosphorus (WP), WP wicks and wedges, and plasticized WP (PWP); hexachloroethane (HC) smoke; smoke plumes from diesel oil fires; fog oil (SGF2), vaporized diesel fuel (DF), polyethylene glycol (PEG200), and IR screener disseminated from generators. Obscurant clouds are modeled in COMBIC as combinations of subclouds having concentrations described by Gaussian instantaneous puffs and continuous plumes. Subclouds move down wind, expand, and perhaps rise because of buoyancy. Optical properties are defined in terms of extinction per unit concentration for the material in each subcloud. Thus, transmittance includes the combined effect of extinction along the observer-target path for every subcloud along that path. Output includes the predicted transmittance at the UV, visual, near-IR, mid-IR, far-IR, and millimeter wavelength (MMW) regions of the electromagnetic spectrum.

2.2.2 *Seeker/Sensor Modeling and Simulation*

In general, any sensor/seeker model or simulation can be used with the methodology described. The definition of a model from a Department of Defense (DoD) modeling and simulation (M&S) master plan **[4]** is a physical, mathematical, or otherwise logical representation of a system, entity, phenomenon, or process. The model or simulation should be interoperable or have the ability to provide services to and accept services from other models and simulations and to use the services so exchanged to enable them to operate effectively together. The model or simulation should have undergone VV&A procedures if the results are to be used for evaluating U.S. Army systems.

The Stinger-RMP missile HWIL simulation is used as an example seeker system to demonstrate the analysis methodology described in this report. The Stinger-RMP HWIL simulation, operated by the Survivability/Lethality Analysis Directorate (SLAD) of ARL, White Sands Missile Range (WSMR), New Mexico, had previously undergone VV&A procedures. A letter **[5]** from the Stinger Product Manager contains a list of authorized simulations that can be used for sources of Stinger performance data. The Stinger-RMP HWIL simulation was validated to the standards developed by the Stinger Simulation Working Group.

2.2.3 *Target/Obscurants/Seeker Computer Routine*

The target/obscurants/seeker (TARG/OB/S) computer routine was developed to provide data to analyze obscurant attenuation effects on seekers by integrating obscurant data generated from COMBIC with seeker target acquisition performance generated from a model, simulation, or test results. The computer routine presently is designed for the three types of obscurants under the specified meteorological conditions, with a specific missile seeker and two aircraft targets that were selected for a study that was conducted. Modifications of the TARG/OB/S FORTRAN 77 code can be made for using other types of obscurants with another seeker against other types of air or ground targets. If different obscurant data are desired, then the COMBIC scenarios need to be run and the file locations specified in the obscurants subroutine of the TARG/OB/S computer routine code. Analysis of different seeker performance against selected targets requires obtaining HWIL simulation, model, or test data summarized in range versus attenuation tables as described in this report. These data would then be inserted in the HWIL subroutine of the TARG/OB/S computer routine code. The basic function of the computer routine is to determine the range where the obscurants attenuate the target's radiated electromagnetic energy to a level below the seeker's operating threshold level in the various spectral bands. The computer routine provides results in the form of range versus target acquisition status for an area of coverage that is 5000 meters to the right, 5000 meters to the left, and 5000 meters in front of the seeker.

2.3 TARG/OB/S Computer Routine Code Structure

The TARG/OB/S computer routine is a six-step process as shown by the flow chart in Figure 2. The first step consists of specifying the target and obscurant initial conditions.

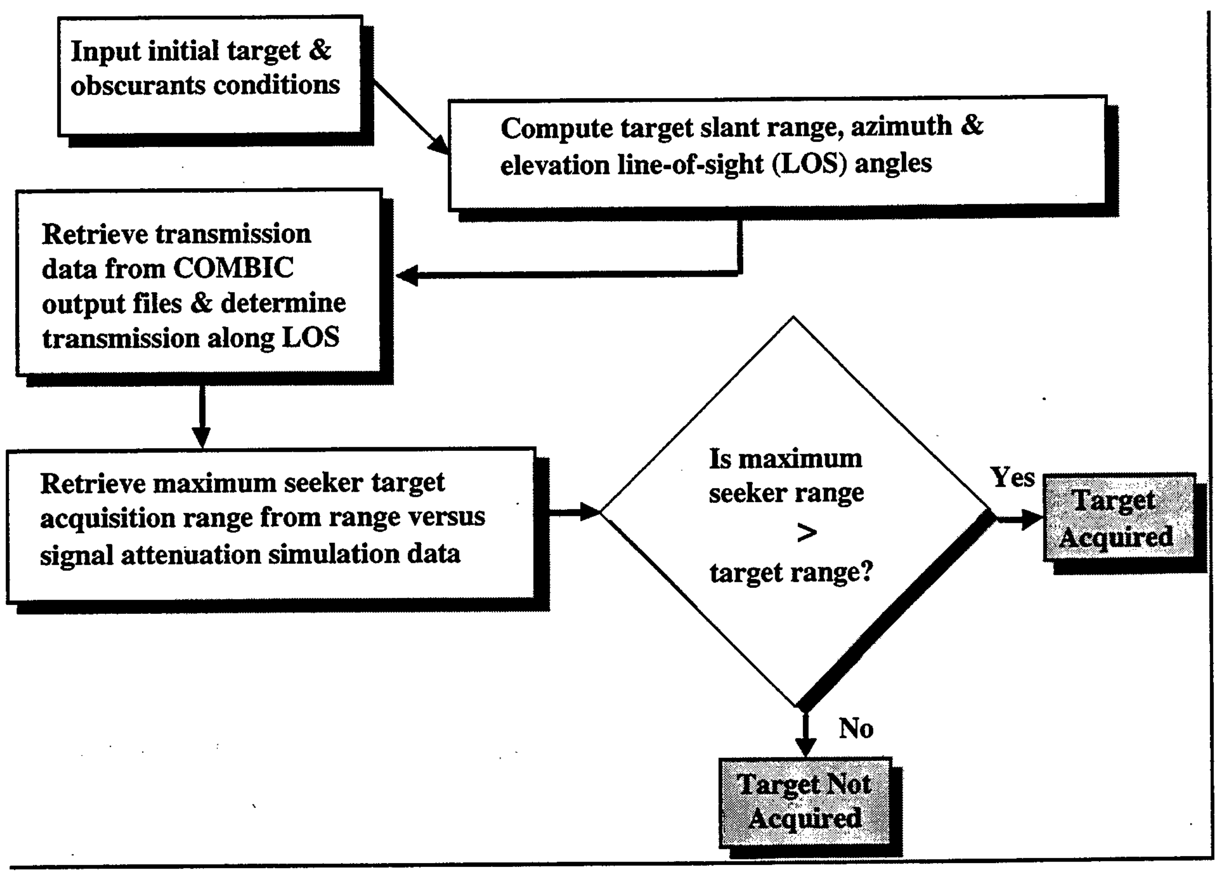

Figure 2. TARG/OB/S Computer Routine Operations Flow Chart.

The second step in the process computes the LOS between the seeker and the target, which is in-bound at some initial distance down range and off range parallel to the down-range axis. The third step retrieves the obscurant transmission level from COMBIC-generated "look-up" tables of transmission values on the LOS of the azimuth and elevation angle of the target. Step 4 retrieves the seeker maximum acquisition range from the HWIL results, also stored in look-up tables. The fifth step compares the maximum seeker range from the HWIL with the actual range of the target computed in Step 2. The sixth and final step determines whether the target is within the seeker range. If the computer range from Step 1 exceeds the maximum seeker range from the HWIL look-up tables, a non-acquisition condition occurs. If the target range is less than the HWIL range, an acquisition condition occurs.

2.4 TARG/OB/S User Interface and Output

This section provides guidance about the TARG/OB/S computer routine user interface through keyboard entry of data, as prompted by the monitor display, and output to be expected.

2.4.1 *Input Data*

The name of the TARG/OB/S FORTRAN 77 program is "targobs.f" and may be obtained by request to the author or organization as listed on the report documentation page, Standard Form 298, which is included with this report. Any modifications needed to represent different obscurants or sensor conditions need to be made in "targobs.f". The present executable file is called "targobs". The program is initiated by typing "targobs" at the computer prompt. The following input prompts appear:

Obscurant type: Dust, M76, or L8A1

Meteorological condition: Categories 1 through 5, as explained in Appendix B, Table B-2 of this report.

Type of obscurant data output desired (monitor display): Graphic or tabular

Target location: Initial ground down range (not slant range) position of the target in meters.

Aircraft type: Rotor or fixed wing

Spectral band: UV or mid-IR

2.4.2 *Output Data and Results*

After the last prompt for input data, the computer routine computes the seeker target acquisition for each time step in the obscurant scenario and for target off-range positions from -5000 to +5000 meters, with the seeker located at 0.0 meter. The following information will be displayed and/or captured to file for printer output:

Section heading: aircraft type, spectral band, initial down-range position, off-range position, target altitude, and speed.

Time-Stepped Output: trial code, trial time in seconds, target azimuth and elevation angles in degrees, transmission along the LOS, target down-range position in meters, seeker-attenuated maximum target acquisition range in meters, target acquisition status as NA = not acquired and A = acquired. The trial code consists of input information to verify the run conditions. For example, "a1uvo2w5m1" means aircraft type 1, UV spectrum, obscurant type 2, wind condition 5, and meteorological condition 1.

2.5 Methodology Application Example

The TARG/OB/S code was run for parameters and conditions established for the example study to demonstrate its application. An example of the TARG/OB/S computer routine input/output for the application study is shown in Appendix A. TARG/OB/S output consists of target position, the transmission along the LOS, maximum seeker target acquisition range possible through the obscurant, and the target acquisition status.

2.5.1 *COMBIC Obscurant Scenarios*

The COMBIC model was run for the M76 IR and L8A1 RP smoke grenades (UV and IR spectral bands, five wind directions, and five meteorological conditions) and vehicular dust obscurant (UV and IR spectral bands, five wind directions, five meteorological conditions, two vehicle speeds, and two vehicle separations). Three hundred obscurant runs were made. The specific conditions modeled are shown in Appendix B.

One type of COMBIC output consists of codes that represent transmission along the LOS through the smoke cloud. The definitions of the COMBIC graphic codes and corresponding transmission levels are shown in Table 1.

Table 1. COMBIC Graphic Codes and Equivalent Transmission Levels

COMBIC Graphic Code	Transmission Level
*	.000 - .001
1	.001 - .050
2	.051 - .100
3	.101 - .150
4	.151 - .200
5	.201 - .250
6	.251 - .300
7	.301 - .350
8	.351 - .400
9	.401 - .450
0	.451 - .500
no value	above .500

Examples of COMBIC transmission graphical output in the UV and IR spectral bands for six L8A1 RP smoke grenades at 1 and 20 seconds after detonation are shown in Figure 3.

2.5.2 *Stinger-RMP Missile HWIL Simulation*

The Stinger-RMP HWIL simulation is a six-degree-of-freedom (DOF) missile fly-out, real-time simulation. The input at the seeker is a signal-injected two-color scene. The output consists of miss distance, probability of hit, lethality and seeker signals. The simulation was run for the seeker target acquisition only, e.g., the simulation was terminated 1.0 second before trigger pull for each target engagement sequence. The block diagram of the Stinger-RMP missile is shown in Figure 4. Atmospheric attenuation in the UV and the IR spectra was electronically simulated by reducing the signal from the UV and IR scenes (target/CM block) as input into the missile electronics circuitry (missile electronics block) of the seeker.

a. Study Geometry

The HWIL simulation study consisted of aircraft frontal attack scenarios. Each scenario consisted of geometries initially starting at 5000 meters down range, off ranges at 500, 1000, 2000, 3000, 4000 and 5000 meters, parallel to the down-range axis. (Note: The HWIL scenarios in this study limited the maximum initial target down-range position to 5 km, not to the maximum seeker target acquisition range known for clear air conditions. Future simulations should start at the known maximum seeker target acquisition range in clear air conditions. However, this procedure will add to the number of runs made and consequently to the time and cost of the study.) Target acquisition attempts were made every 200 meters, starting at 5000

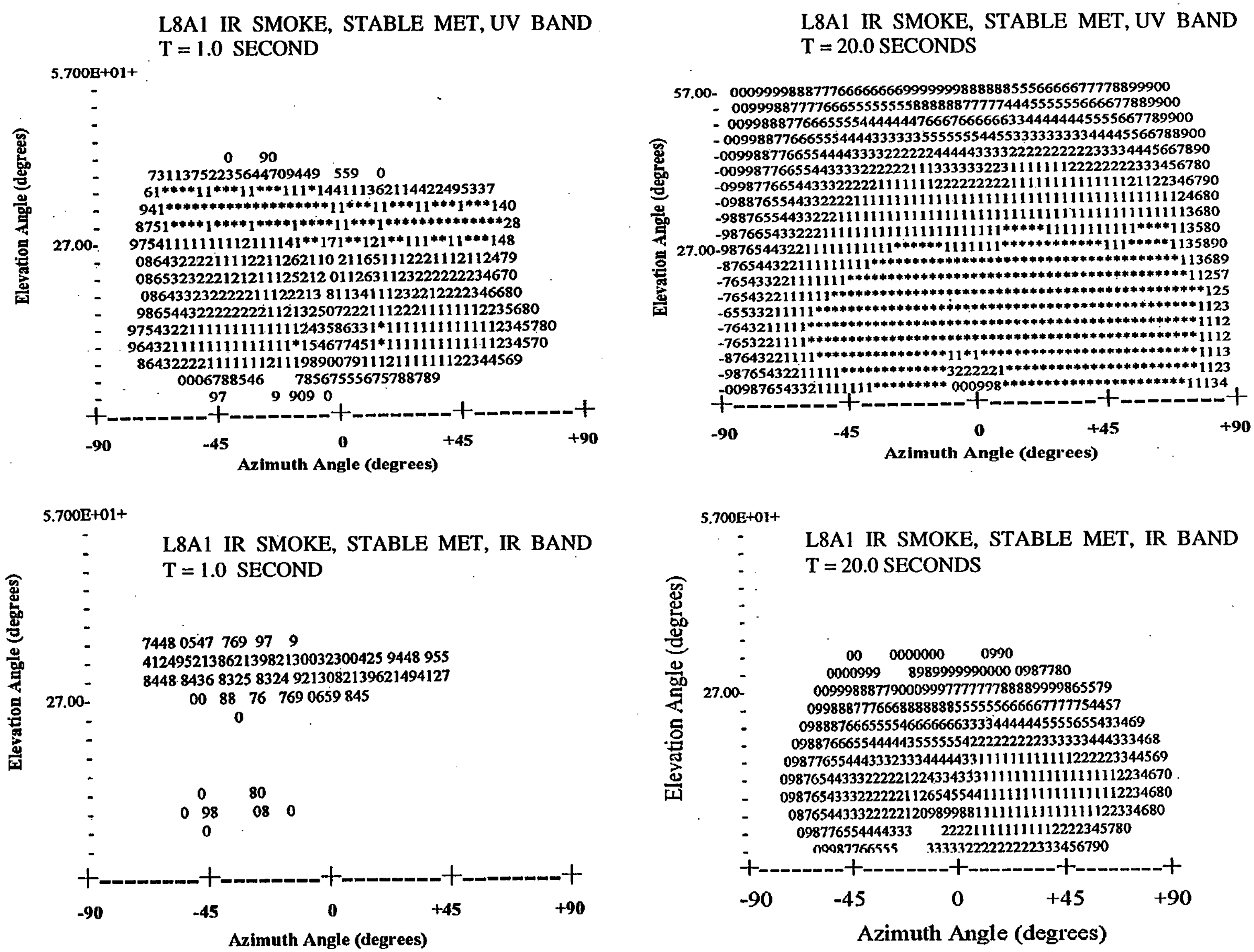

Figure 3. Example of COMBIC Obscurant Data.

meters to 0 meters down range, for each off range. For each scenario, the target signal into the seeker electronics was attenuated in the UV and the IR seeker circuitry from 0.0 to 0.90, in increments of 0.10. Above 0.90, simulations were run for 0.95 and 0.999 signal attenuation levels. The attenuation level settings were chosen to coincide with the COMBIC codes and the corresponding transmission values. The 0.0 to 0.90, 0.95, 0.999 attenuation levels in the HWIL are equal to the 1.0 to 0.10, 0.05 and 0.001 transmission (1.0 - attenuation) levels computed by COMBIC, respectively. The results from the HWIL were target acquisition range in the UV and IR seeker modes as functions of transmission and target position. A total of 8,213 acquisition attempts was completed during this study.

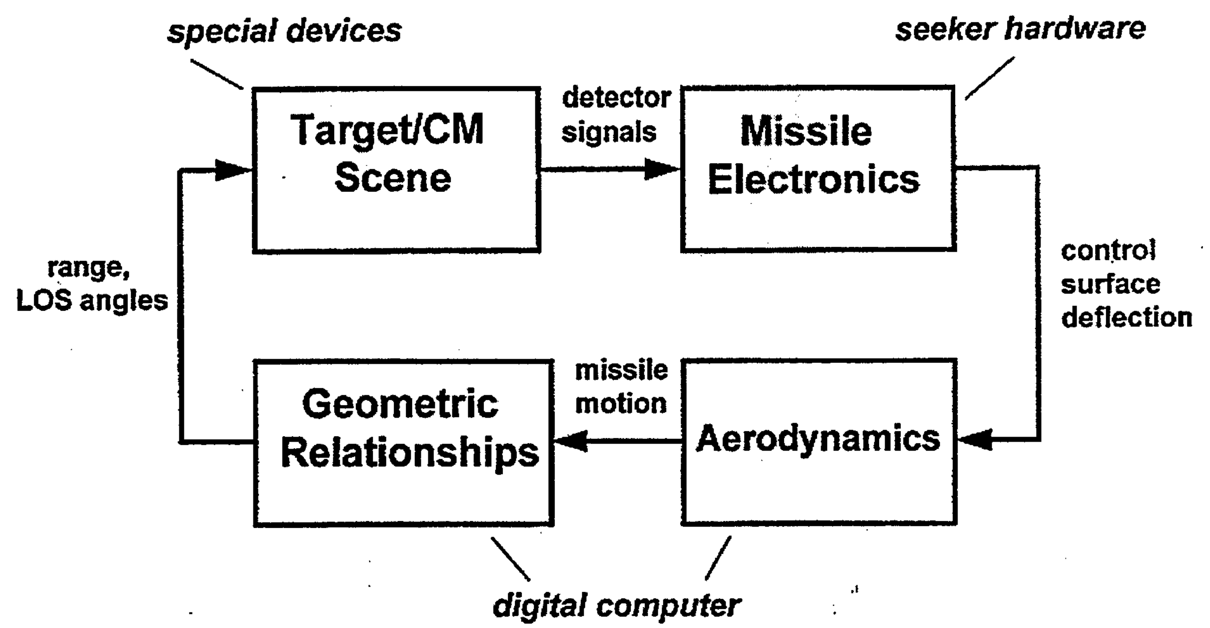

Figure 4. Missile HWIL Simulation Block Diagram.

b. HWIL Output

The HWIL data output for each engagement includes target type and position (off range, down range, and slant range in meters), the LOS azimuth and elevation angles, and atmospheric transmission value settings in the UV and IR modes. HWIL output in graphical form consists of a silhouette of the target depicting the direction of flight down range to the Linebacker denoted as G (gunner), symbols on the grid where the seeker acquired the target, and other useful information. A sample output from the HWIL simulation is shown in Figure 5, with detailed run information removed for security classification reasons. Each "*" shown on the graph represents the down-range position along the off-range target path where the seeker was able to acquire the target. Likewise, each "∘" represents the down-range position along the off-range target path where the seeker did not acquire the target.

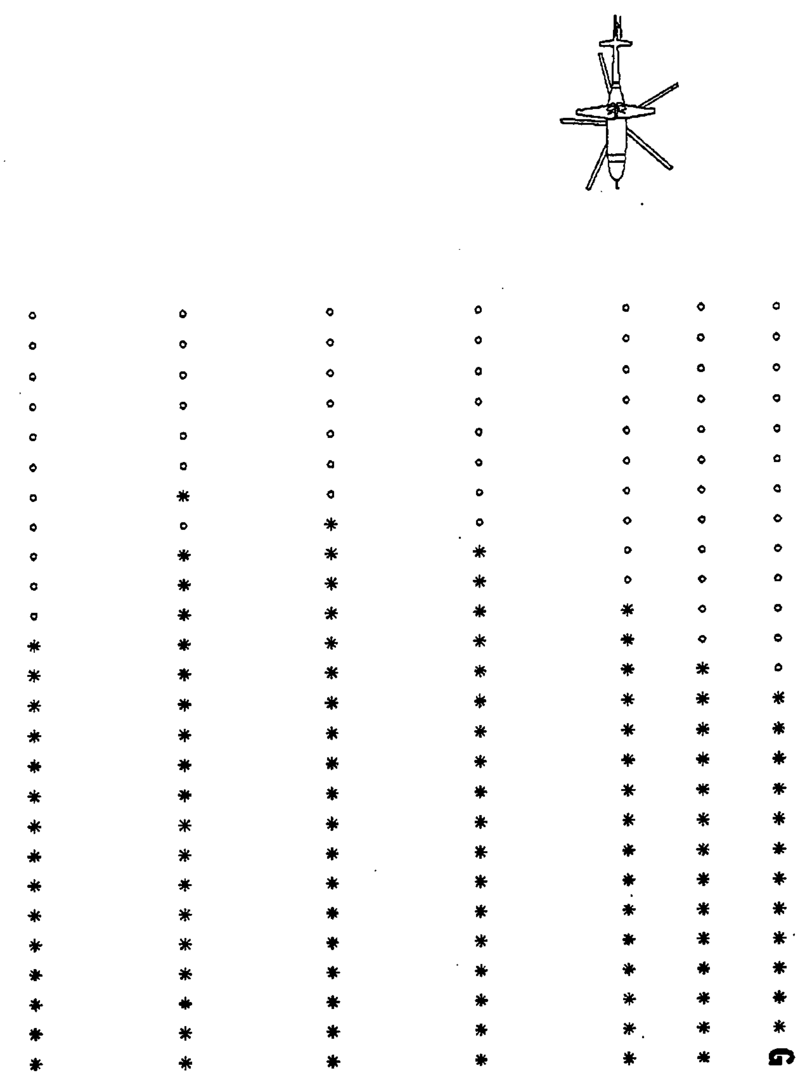

Figure 5. Example of Seeker HWIL Output.

The HWIL output data were consolidated into two graphs consisting of the seeker UV and IR modes against each target. A generalized example of a consolidated graph is shown in Figure 6.

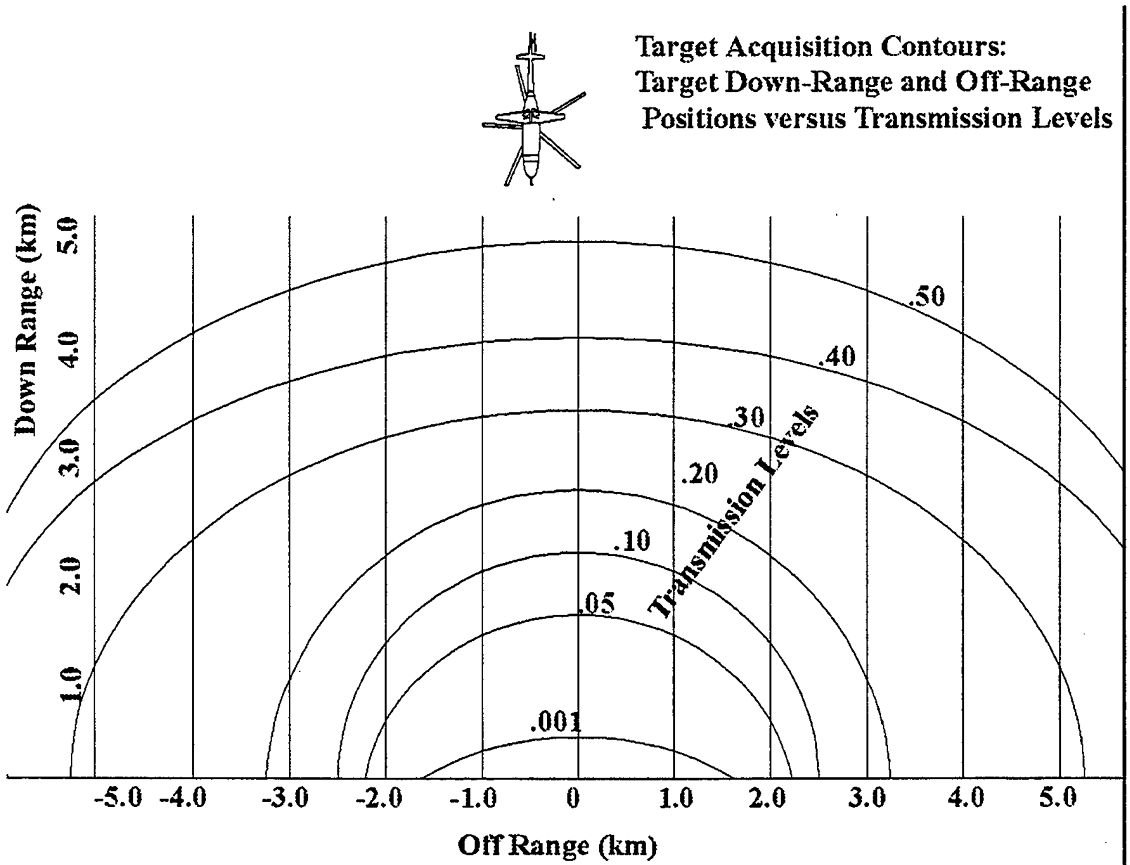

Figure 6. Sample Consolidated Seeker HWIL Target Acquisition Data.

Each contour line represents the maximum seeker target acquisition slant range, if the transmission along the LOS were at the level shown on the graph. The vertical lines represent the target path along a straight line from 5000 to 0.0 meters at each off range, parallel to the vertical axis, at constant altitude and speed. In the Bradley Linebacker analysis, two primary threat targets were run, so four consolidated master graphs (two targets, two seeker acquisition modes) were used as the basis for seeker performance in the study.

2.5.3 *TARG/OB/S Computer Routine Results*

An example of the acquisition range profile graphical output obtained from the computer routine is shown in Figure 7. The helicopter symbol shows the direction of the attacking aircraft. Positions where the seeker acquired the target are designated by the "*" symbols on the graph. The areas where "no symbol" appears are where the seeker did not acquire the target because the energy was attenuated below the minimum energy required for the seeker to operate. The maximum acquisition ranges are shown by the top-most *s on the graph.

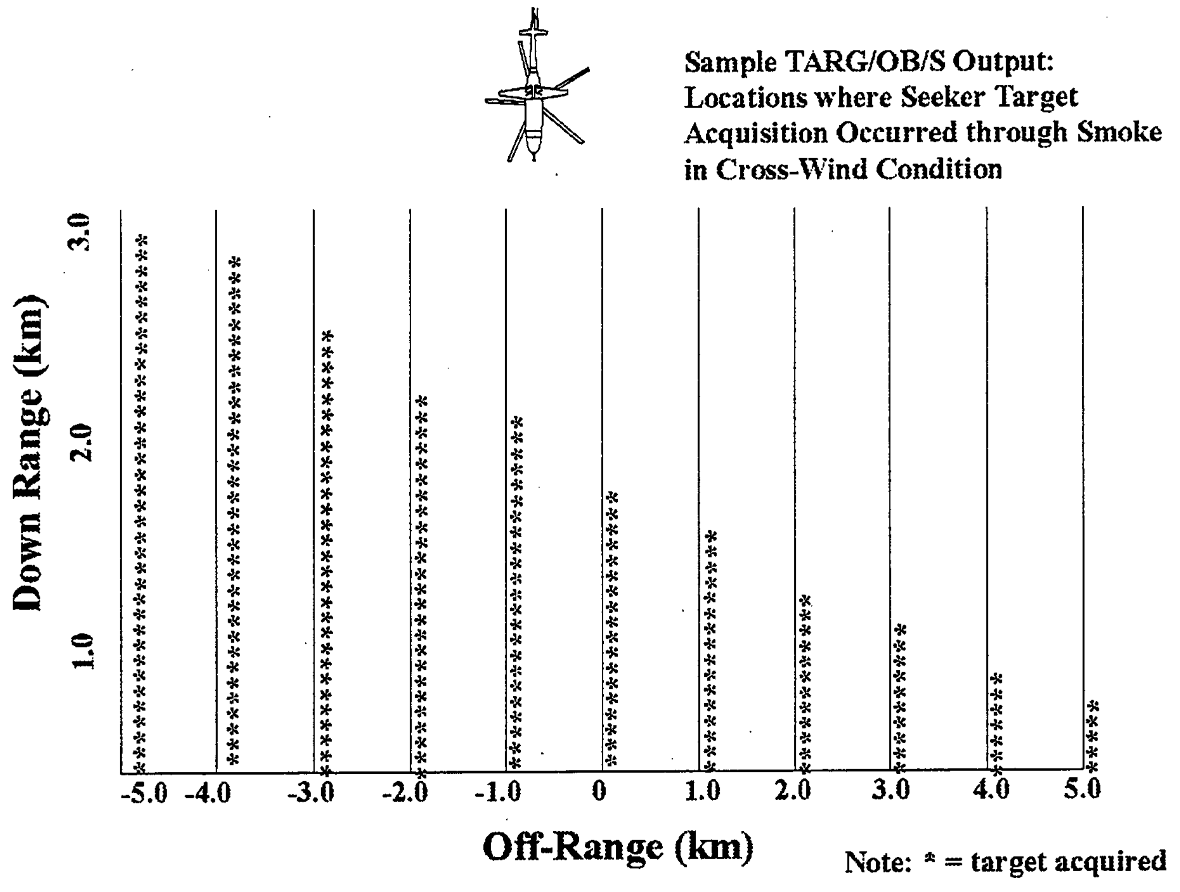

Figure 7. Example of TARG/OB/S Computer Routine Results in Graphical Form.

2.5.4 *Example of TARG/OB/S Computer Routine Calculations*

Step 1: The target is initially at 3000 meters down range, 0.0 meters off range (head-on), constant altitude of 150 meters and traveling at 125 m/sec. The Bradley Linebacker crew is aware of the attack and deploys the L8A1 self-defensive grenades. Will the seeker be able to acquire the target 20 seconds after the grenades are released? The target travels 2500 meters after 20 seconds and is 500 meters from the Linebacker. The LOS elevation angle is 16.7° [slant range = square root of ($500^2 + 150^2 + 0.0^2$) = 522 meters, $\sin^{-1}$ (150 meters/522 meters) x 57.3° = 16.7°]. The LOS azimuth angle is 0.0°. Step 2: Using Figure 3, the transmission code in the IR band at 20 seconds for 16.7° elevation and 0.0° azimuth is "4," which is between .15 and .20 transmission from Table 1. Using Figure 3, the transmission code in the UV band at 20 seconds for 16.7° elevation and 0.0° azimuth is "*," which is around .001 transmission from Table 1. Step 3: Using Figure 6, the maximum target acquisition range is 2500 meters for the IR seeker mode and 500 meters for the UV seeker mode. Steps 4 and 5: Since the IR seeker mode can acquire the target as far away as 2500 meters and the target is at 500 meters, the seeker would acquire the target. In the UV mode, since the seeker can acquire the target as far away as 500 meters and the target is at 500 meters, the seeker would barely acquire the target. These are only examples and are not actual Stinger seeker performance results.

3. ANALYSIS TECHNIQUES

The analysis of seeker performance was based on (1) a comparison of the seeker maximum target acquisition range through obscurants with the U.S. Army requirements and the demonstrated clear air target acquisition ranges from field experiments and tests, and (2) a comparison of the target acquisition range coverage (TARC) figure of merit estimates, in percent, for various target, seeker and obscurant conditions, and (3) seeker target acquisition range capability versus optical depth (OD) levels.

3.1 Maximum Target Acquisition Range

Maximum target acquisition ranges were compared at -1.0, 0.0, and +1.0 km off-range positions, which were chosen in order to be consistent with the clear air test program.

3.2 TARC Estimates

The TARC estimates were statistically analyzed for each target-seeker mode combination to determine the significance of impact of the obscurant type and wind direction parameters on seeker performance. The significance of impact was qualified using an approved definition as minimal, low, or high impact, based on the magnitude of the TARC estimate. The TARC estimate is the ratio of the total distance that the seeker is able to acquire the target through obscurants to the total distance the target could travel throughout the frontal attack area. The equation for the TARC value is shown below.

$$\text{TARC}(\%) = \frac{\sum Src_i}{\sum Tdt_i}, \text{ for } i = -5 \text{ to } +5 \qquad (3)$$

in which

TARC (%) equals the percent target acquisition range coverage in the total frontal attack area, "i" equals target off-range paths from -5000 meters to +5000 meters, $\sum Src_i$ equals the summation of the seeker target acquisition range covered in the frontal attack area, and $\sum Tdt_i$ equals the summation of the total distance that the target could travel in the frontal attack area.

3.2.1 *Example of Analysis Methodology Calculations*

Using the results shown in Figure 7, the maximum target acquisition range is approximately 2.0, 1.8, and 1.5 kilometers at -1.0, 0.0, and +1.0 kilometer off ranges, respectively. The TARC estimate, using Equation (3) and approximate target acquisition range values in Figure 7, is computed as follows: Src = 19.2 kilometers (3.0 + 2.7 + 2.5 + 2.2 + 2.0 + 1.8 + 1.5 + 1.2 + 1.0 +.80 + .50), Tdt = 33.0 kilometers (3.0 kilometers/path times 11 paths), and TARC = (19.2/33.0) times 100 = 58%. This estimate indicates that the seeker was able to acquire the target along 58% of the target paths traveled in the frontal attack area during the specified obscurant conditions.

3.3 Optical Depth

Target acquisition range is related to the amount of target radiant energy received by the seeker and is a function of target aspect (presented area) and the amount of obscurant in the LOS between the seeker and the target. The target aspect can be related in terms of target down-range and off-range position. The amount of obscurants in the LOS is indicated by the "αCL" or optical depth (OD) level. Weapon systems requirements for target acquisition in obscurants are usually specified as the maximum target acquisition range achievable in obscurants at threat "αCL" levels. Using the Beer-Bouguer Transmittance Law, Equation (2), αCL can be solved from the transmission equation as follows:

$$OD = \alpha CL = -\ln T \qquad (4)$$

in which

OD = optical depth; T = transmission or transmissivity, percent or decimal, unitless; α = mass extinction coefficient (from chamber test) of the obscurant, m^2/gm; CL = the concentration-path length of the obscurant cloud. The output from the seeker HWIL simulation consists of maximum target acquisition range versus transmission levels, as shown in Figure 6. The transmissions can be changed to αCL levels using Equation (4). As an example, if the seeker were required to operate at in αCL levels of 2.0 to 3.0, this would be equivalent to 0.14 to 0.05 transmission, respectively. Using the seeker performance contours in Figure 6, the maximum target acquisition range that could be achieved would be approximately 2000 meters. Requirements for U.S. Army electro-optical systems are usually stated in terms of target acquisition range to achieve when operating in obscurants at the specified OD levels. For example, the requirements might state that a particular seeker or sensor must acquire the target at 3000 meters when operating through obscurants with an OD level of 2.0. Using the Beer-Bouguer Transmission equation (2) when OD is equal to 2.0, transmission is equal to 0.14. As an example of application of the acquisition range versus transmission graph in Figure 6, the maximum target acquisition range that the seeker could achieve would be 2000 to 3000 meters, depending on the target aspect. The seeker would barely meet the requirement against the target at side view and would not meet the requirement against the target at frontal view.

4. CONCLUSION AND RECOMMENDATION

Sophisticated modern weaponry uses a myriad of electro-optical sensing devices for target detection and acquisition, which are limited by the battlefield environment. Obscurants used on the battlefield can be produced by combustion of materials such as phosphorus, condensation of vapor such as diesel or fog oil, or dissemination of millimeter wave (MMW) fibers. Dust produced by artillery and moving vehicles is an unavoidable by-product of the battlefield. Self-defensive smoke can protect U.S. forces from target acquisition by the enemy but can be a double edged sword by rendering main weapons ineffective and thereby decreasing survivability. Most battlefield obscurants attenuate radiant energy used by "smart" weapons to acquire and lock onto the target. Obscurant attenuation effects degrade sensor/seeker target acquisition performance. Field testing of each new weapon system in the appropriate battlefield environments would be ideal but has been found to be both impractical and costly. Analysis of weapon sensor/seeker performance in the presence of obscurants, using approved computer models and simulations provides a timely, comprehensive, and cost-effective method to assess electro-optical seeker performance in degraded atmospheric conditions that can be expected on the battlefield.

REFERENCES

1. Andrese, J.A. "Draft Evaluation Support Area Analysis Report, Bradley Fighting Vehicle System - Enhanced/Linebacker Stinger-RMP Missile Target Acquisition Performance in Obscurants." U.S. Army Research Laboratory, Aberdeen Proving Ground, MD, August 1996 (SECRET/NOFORN).

2. Sutherland, R. "Combined Obscuration Model for Battlefield-Induced Contaminants (COMBIC)." TR-0221011, Report, EOSAEL 87, Vol. II, Atmospherics Sciences Laboratory, October 1987 (UNCLASSIFIED).

3. Letter, Office of the Director, U.S. Army Research laboratory, Battlefield Environment Directorate, Subject: COMBIC Verification and Validation, 1 July 1996 (UNCLASSIFIED).

4. Department of Defense. "DoD Modeling and Simulation (M&S) Master Plan" DoD 5000.59-P, October 1995

5. Memorandum for Stinger Simulation Users, SFAE-MSL-ST-SE, Subject: Use of Authorized Stinger Sources, 31 May 1996 (UNCLASSIFIED)

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APPENDIX A

EXAMPLE OF TARG/OB/S COMPUTER ROUTINE INPUT AND OUTPUT

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EXAMPLE OF TARG/OB/S COMPUTER ROUTINE INPUT AND OUTPUT

```
INPUT OBSCURANT TYPE> DUST=1  M76=2  L8A1=3
2
 Specify Met Condition 1,2,3,4 or 5
1
 Want Obscurants Graphics?  yes=1   no=0
1
 Specify Target Parameters- downrange (m) =
3000.
 Specify Target  RW=1  FW=2
1
 Specify Band   uv=1  ir=2
1
 Tar= 1 Bnd=uv Init Dwn Rng=  3000. Off-Rng= -5000. Alt= xx V=xx
 ------------------------------


 5.700E+01+
       -
       -
       -
       -
       -
       -
       -
       -
       -
 2.700E+01+
       -
       -
       -
       -
       -
       -
       -
       -
       -
       -
       +-------------+-------------+-------------+-------------+----
   -9.000E+01    -4.500E+01      .000E+00     4.500E+01     9.000E+01
a1uvo2w1m1 T=  0. az= -59. el=  0. tr=1.000 TxR= 3000.      Results not shown due to classifcation.
 5.700E+01+               0999888889900
       -                   09877666666677890
       -                  098765544444445567890
       -                 09765543333223333456790
       -                 98654332222111222334578O
       -                0875432221111111122345780
       -                986532211111111111223579
       -                9754321111111111111123570
       -                975432111111****11111123580
       -                975432111111********111123570
 2.700E+01+            07643211111***********11112469
       -                08643211111*************111124670
       -                 97542211111**************111122469
       -                  8653211111****************11111248
       -                  086432111111*****************111140
       -                   9864322111111*****************1138
```

```
  -                  98654321111111*************11139
  -                   087643322111111111111111111126
  -                     0876543322221111111112222246
  -                       098766554444444555677778O
  +-------------+-------------+-------------+-------------+----
-9.000E+01   -4.500E+01    .000E+00   4.500E+01    9.000E+01
aluvo2wlml T= 10. az= -65. el=  0. tr=1.000 TxR= 2383.     Results not shown due to classifcation.

5.700E+01+
  -
  -
  -
  -
  -
  -
  -
  -                             9888890
  -                            97544445680
2.700E+01+                    9643211223570
  -                            06421111111258
  -                            852111***111360
  -                            74111******1137
  -                            7311********1138
  -                            8411*********1139
  -                            05211*********116
  -                             84111********126
  -                              74211111111124
  -                               964322223458
  +-------------+-------------+-------------+-------------+----
-9.000E+01   -4.500E+01    .000E+00   4.500E+01    9.000E+01
aluvo2wlml T= 20. az= -71. el=  0. tr=1.000 TxR= 1765.     Results not shown due to classifcation.

5.700E+01+
  -
  -
  -
  -
  -
  -
  -
  -
  -
2.700E+01+
  -
  -                                  00
  -                                9533347
  -                               831111126
  -                               511****126
  -                               31******129
  -                               41*******18
  -                               831*****13
  -                                95211236
  +-------------+-------------+-------------+-------------+----
-9.000E+01   -4.500E+01    .000E+00   4.500E+01    9.000E+01
aluvo2wlml T= 30. az= -77. el=  0. tr=1.000 TxR= 1148.     Results not shown due to classifcation.
```

```
5.700E+01+
        -
        -
        -
        -
        -
        -
        -
        -
        -
2.700E+01+
        -
        -
        -
        -                              00
        -                            0411138
        -                            31***118
        -                           02*****14
        -                            41****15
        -                             621127
        +-------------+-------------+-------------+-------------+----
  -9.000E+01    -4.500E+01     .000E+00    4.500E+01     9.000E+01
aluvo2wlml T= 40. az= -84. el=  0. tr=1.000 TxR=  531.       Results not shown due to classifcation.
```

```
5.700E+01+
        -
        -
        -
        -
        -
        -
        -
        -
        -
2.700E+01+
        -
        -
        -
        -
        -
        -                              511130
        -                              71****2
        -                              81****2
        -                               82113
        +-------------+-------------+-------------+-------------+----
  -9.000E+01    -4.500E+01     .000E+00    4.500E+01     9.000E+01
aluvo2wlml T= 60. az= -91. el=  0. tr=1.000 TxR=  0.       Results not shown due to classifcation.
```

EXAMPLE 2. INPUT AND OUTPUT WITHOUT OBSCURANTS GRAPHICS

INPUT OBSCURANT TYPE> DUST=1 M76=2 L8A1=3
2
Specify Met Condition 1,2,3,4 or 5

```
1
 Want Obscurants Graphics?  yes=1   no=0
0
 Specify Target Parameters- downrange (m) =
3000.
 Specify Target  RW=1  FW=2
1
 Specify Band   uv=1  ir=2
1
 Tar= 1 Bnd=uv Init Dwn Rng=  3000. Off-Rng= -5000. Alt=  30. V=120.K  62.m/s
```

RUN CODE	TIME	TARGET POSITION	TRANS. ON LOS	TARGET DISTANCE	SEEKER TARGET ACQUISITION

```
aluvo2w1m1 T=  0. az= -59. el=  0. tr=1.000 TxR= 3000.
aluvo2w1m1 T= 10. az= -65. el=  0. tr=1.000 TxR= 2383.
aluvo2w1m1 T= 20. az= -71. el=  0. tr=1.000 TxR= 1765.
aluvo2w1m1 T= 30. az= -77. el=  0. tr=1.000 TxR= 1148.
aluvo2w1m1 T= 40. az= -84. el=  0. tr=1.000 TxR=  531.
-----------------------------
aluvo2w2m1 T=  0. az= -59. el=  0. tr=1.000 TxR= 3000.
aluvo2w2m1 T= 10. az= -65. el=  0. tr=0.350 TxR= 2383.
aluvo2w2m1 T= 20. az= -71. el=  0. tr=1.000 TxR= 1765.
aluvo2w2m1 T= 30. az= -77. el=  0. tr=1.000 TxR= 1148.
aluvo2w2m1 T= 40. az= -84. el=  0. tr=1.000 TxR=  531.
-----------------------------
aluvo2w3m1 T=  0. az= -59. el=  0. tr=1.000 TxR= 3000.
aluvo2w3m1 T= 10. az= -65. el=  0. tr=1.000 TxR= 2383.
aluvo2w3m1 T= 20. az= -71. el=  0. tr=1.000 TxR= 1765.
aluvo2w3m1 T= 30. az= -77. el=  0. tr=1.000 TxR= 1148.
aluvo2w3m1 T= 40. az= -84. el=  0. tr=1.000 TxR=  531.
-----------------------------
aluvo2w4m1 T=  0. az= -59. el=  0. tr=1.000 TxR= 3000.
aluvo2w4m1 T= 10. az= -65. el=  0. tr=1.000 TxR= 2383.
aluvo2w4m1 T= 20. az= -71. el=  0. tr=1.000 TxR= 1765.
aluvo2w4m1 T= 30. az= -77. el=  0. tr=1.000 TxR= 1148.
aluvo2w4m1 T= 40. az= -84. el=  0. tr=1.000 TxR=  531.
-----------------------------
aluvo2w5m1 T=  0. az= -59. el=  0. tr=1.000 TxR= 3000.
aluvo2w5m1 T= 10. az= -65. el=  0. tr=1.000 TxR= 2383.
aluvo2w5m1 T= 20. az= -71. el=  0. tr=1.000 TxR= 1765.
aluvo2w5m1 T= 30. az= -77. el=  0. tr=1.000 TxR= 1148.
aluvo2w5m1 T= 40. az= -84. el=  0. tr=1.000 TxR=  531.
 Tar= 1 Bnd=uv Init Dwn Rng=  3000. Off-Rng= -4000. A
-----------------------------
aluvo2w1m1 T=  0. az= -53. el=  0. tr=1.000 TxR= 3000.
aluvo2w1m1 T= 10. az= -59. el=  0. tr=1.000 TxR= 2383.
aluvo2w1m1 T= 20. az= -66. el=  0. tr=1.000 TxR= 1765.
aluvo2w1m1 T= 30. az= -74. el=  0. tr=1.000 TxR= 1148.
aluvo2w1m1 T= 40. az= -82. el=  0. tr=1.000 TxR=  531.
-----------------------------
aluvo2w2m1 T=  0. az= -53. el=  0. tr=1.000 TxR= 3000.
aluvo2w2m1 T= 10. az= -59. el=  0. tr=0.350 TxR= 2383.
aluvo2w2m1 T= 20. az= -66. el=  0. tr=1.000 TxR= 1765.
aluvo2w2m1 T= 30. az= -74. el=  0. tr=1.000 TxR= 1148.
```

Results in this column are not shown due to classification.

aluvo2w2m1 T= 40. az= -82. el= 0. tr=1.000 TxR= 531.

---

aluvo2w3m1 T= 0. az= -53. el= 0. tr=1.000 TxR= 3000.
aluvo2w3m1 T= 10. az= -59. el= 0. tr=0.500 TxR= 2383.
aluvo2w3m1 T= 20. az= -66. el= 0. tr=1.000 TxR= 1765.
aluvo2w3m1 T= 30. az= -74. el= 0. tr=1.000 TxR= 1148.
aluvo2w3m1 T= 40. az= -82. el= 0. tr=1.000 TxR= 531.

---

aluvo2w4m1 T= 0. az= -53. el= 0. tr=1.000 TxR= 3000.
aluvo2w4m1 T= 10. az= -59. el= 0. tr=1.000 TxR= 2383.
aluvo2w4m1 T= 20. az= -66. el= 0. tr=1.000 TxR= 1765.
aluvo2w4m1 T= 30. az= -74. el= 0. tr=1.000 TxR= 1148.
aluvo2w4m1 T= 40. az= -82. el= 0. tr=1.000 TxR= 531.

---

aluvo2w5m1 T= 0. az= -53. el= 0. tr=1.000 TxR= 3000.
aluvo2w5m1 T= 10. az= -59. el= 0. tr=1.000 TxR= 2383.
aluvo2w5m1 T= 20. az= -66. el= 0. tr=1.000 TxR= 1765.
aluvo2w5m1 T= 30. az= -74. el= 0. tr=1.000 TxR= 1148.
aluvo2w5m1 T= 40. az= -82. el= 0. tr=1.000 TxR= 531.
Tar= 1 Bnd=uv Init Dwn Rng= 3000. Off-Rng= -3000. A

---

aluvo2w1m1 T= 0. az= -45. el= 0. tr=1.000 TxR= 3000.
aluvo2w1m1 T= 10. az= -52. el= 0. tr=1.000 TxR= 2383.
aluvo2w1m1 T= 20. az= -60. el= 0. tr=1.000 TxR= 1765.
aluvo2w1m1 T= 30. az= -69. el= 1. tr=1.000 TxR= 1148.
aluvo2w1m1 T= 40. az= -80. el= 1. tr=1.000 TxR= 531.

---

aluvo2w2m1 T= 0. az= -45. el= 0. tr=1.000 TxR= 3000.
aluvo2w2m1 T= 10. az= -52. el= 0. tr=0.400 TxR= 2383.
aluvo2w2m1 T= 20. az= -60. el= 0. tr=1.000 TxR= 1765.
aluvo2w2m1 T= 30. az= -69. el= 1. tr=1.000 TxR= 1148.
aluvo2w2m1 T= 40. az= -80. el= 1. tr=1.000 TxR= 531.

---

aluvo2w3m1 T= 0. az= -45. el= 0. tr=1.000 TxR= 3000.
aluvo2w3m1 T= 10. az= -52. el= 0. tr=0.500 TxR= 2383.
aluvo2w3m1 T= 20. az= -60. el= 0. tr=1.000 TxR= 1765.
aluvo2w3m1 T= 30. az= -69. el= 1. tr=1.000 TxR= 1148.
aluvo2w3m1 T= 40. az= -80. el= 1. tr=1.000 TxR= 531.

---

aluvo2w4m1 T= 0. az= -45. el= 0. tr=1.000 TxR= 3000.
aluvo2w4m1 T= 10. az= -52. el= 0. tr=1.000 TxR= 2383.
aluvo2w4m1 T= 20. az= -60. el= 0. tr=1.000 TxR= 1765.
aluvo2w4m1 T= 30. az= -69. el= 1. tr=1.000 TxR= 1148.
aluvo2w4m1 T= 40. az= -80. el= 1. tr=1.000 TxR= 531.

---

aluvo2w5m1 T= 0. az= -45. el= 0. tr=1.000 TxR= 3000.
aluvo2w5m1 T= 10. az= -52. el= 0. tr=1.000 TxR= 2383.
aluvo2w5m1 T= 20. az= -60. el= 0. tr=1.000 TxR= 1765.
aluvo2w5m1 T= 30. az= -69. el= 1. tr=1.000 TxR= 1148.
aluvo2w5m1 T= 40. az= -80. el= 1. tr=1.000 TxR= 531.
Tar= 1 Bnd=uv Init Dwn Rng= 3000. Off-Rng= -2000.

---

aluvo2w1m1 T= 0. az= -34. el= 0. tr=1.000 TxR= 3000.
aluvo2w1m1 T= 10. az= -40. el= 1. tr=1.000 TxR= 2383.
aluvo2w1m1 T= 20. az= -49. el= 1. tr=1.000 TxR= 1765.
aluvo2w1m1 T= 30. az= -60. el= 1. tr=1.000 TxR= 1148.
aluvo2w1m1 T= 40. az= -75. el= 1. tr=1.000 TxR= 531.

---

aluvo2w2m1 T= 0. az= -34. el= 0. tr=1.000 TxR= 3000.
aluvo2w2m1 T= 10. az= -40. el= 1. tr=0.450 TxR= 2383.
aluvo2w2m1 T= 20. az= -49. el= 1. tr=1.000 TxR= 1765.
aluvo2w2m1 T= 30. az= -60. el= 1. tr=1.000 TxR= 1148.
aluvo2w2m1 T= 40. az= -75. el= 1. tr=1.000 TxR= 531.

---

aluvo2w3m1 T= 0. az= -34. el= 0. tr=1.000 TxR= 3000.
aluvo2w3m1 T= 10. az= -40. el= 1. tr=0.500 TxR= 2383.
aluvo2w3m1 T= 20. az= -49. el= 1. tr=1.000 TxR= 1765.
aluvo2w3m1 T= 30. az= -60. el= 1. tr=1.000 TxR= 1148.
aluvo2w3m1 T= 40. az= -75. el= 1. tr=1.000 TxR= 531.

---

aluvo2w4m1 T= 0. az= -34. el= 0. tr=1.000 TxR= 3000.
aluvo2w4m1 T= 10. az= -40. el= 1. tr=1.000 TxR= 2383.
aluvo2w4m1 T= 20. az= -49. el= 1. tr=1.000 TxR= 1765.
aluvo2w4m1 T= 30. az= -60. el= 1. tr=1.000 TxR= 1148.
aluvo2w4m1 T= 40. az= -75. el= 1. tr=1.000 TxR= 531.

---

aluvo2w5m1 T= 0. az= -34. el= 0. tr=1.000 TxR= 3000.
aluvo2w5m1 T= 10. az= -40. el= 1. tr=1.000 TxR= 2383.
aluvo2w5m1 T= 20. az= -49. el= 1. tr=1.000 TxR= 1765.
aluvo2w5m1 T= 30. az= -60. el= 1. tr=1.000 TxR= 1148.
aluvo2w5m1 T= 40. az= -75. el= 1. tr=1.000 TxR= 531.
Tar= 1 Bnd=uv Init Dwn Rng= 3000. Off-Rng= -1000. A

---

aluvo2w1m1 T= 0. az= -18. el= 1. tr=1.000 TxR= 3000.
aluvo2w1m1 T= 10. az= -23. el= 1. tr=1.000 TxR= 2383.
aluvo2w1m1 T= 20. az= -30. el= 1. tr=1.000 TxR= 1765.
aluvo2w1m1 T= 30. az= -41. el= 1. tr=1.000 TxR= 1148.
aluvo2w1m1 T= 40. az= -62. el= 2. tr=1.000 TxR= 531.

---

aluvo2w2m1 T= 0. az= -18. el= 1. tr=1.000 TxR= 3000.
aluvo2w2m1 T= 10. az= -23. el= 1. tr=0.500 TxR= 2383.
aluvo2w2m1 T= 20. az= -30. el= 1. tr=1.000 TxR= 1765.
aluvo2w2m1 T= 30. az= -41. el= 1. tr=1.000 TxR= 1148.
aluvo2w2m1 T= 40. az= -62. el= 2. tr=1.000 TxR= 531.

---

aluvo2w3m1 T= 0. az= -18. el= 1. tr=1.000 TxR= 3000.
aluvo2w3m1 T= 10. az= -23. el= 1. tr=0.500 TxR= 2383.
aluvo2w3m1 T= 20. az= -30. el= 1. tr=1.000 TxR= 1765.
aluvo2w3m1 T= 30. az= -41. el= 1. tr=1.000 TxR= 1148.
aluvo2w3m1 T= 40. az= -62. el= 2. tr=1.000 TxR= 531.

---

aluvo2w4m1 T= 0. az= -18. el= 1. tr=1.000 TxR= 3000.
aluvo2w4m1 T= 10. az= -23. el= 1. tr=1.000 TxR= 2383.
aluvo2w4m1 T= 20. az= -30. el= 1. tr=1.000 TxR= 1765.
aluvo2w4m1 T= 30. az= -41. el= 1. tr=1.000 TxR= 1148.
aluvo2w4m1 T= 40. az= -62. el= 2. tr=1.000 TxR= 531.

---

aluvo2w5m1 T= 0. az= -18. el= 1. tr=1.000 TxR= 3000.
aluvo2w5m1 T= 10. az= -23. el= 1. tr=0.350 TxR= 2383.
aluvo2w5m1 T= 20. az= -30. el= 1. tr=1.000 TxR= 1765.
aluvo2w5m1 T= 30. az= -41. el= 1. tr=1.000 TxR= 1148.
aluvo2w5m1 T= 40. az= -62. el= 2. tr=1.000 TxR= 531.
Tar= 1 Bnd=uv Init Dwn Rng= 3000. Off-Rng= xx. Alt=xx

---

aluvo2w1m1 T= 0. az= 0. el= 1. tr=1.000 TxR= 3000.
aluvo2w1m1 T= 10. az= 0. el= 1. tr=0.500 TxR= 2383.

```
aluvo2w1m1 T= 20. az=  0. el=  1. tr=1.000 TxR= 1765.
aluvo2w1m1 T= 30. az=  0. el=  1. tr=1.000 TxR= 1148.
aluvo2w1m1 T= 40. az=  0. el=  3. tr=1.000 TxR=  531.
------------------------------
aluvo2w2m1 T=  0. az=  0. el=  1. tr=1.000 TxR= 3000.
aluvo2w2m1 T= 10. az=  0. el=  1. tr=0.500 TxR= 2383.
aluvo2w2m1 T= 20. az=  0. el=  1. tr=1.000 TxR= 1765.
aluvo2w2m1 T= 30. az=  0. el=  1. tr=1.000 TxR= 1148.
aluvo2w2m1 T= 40. az=  0. el=  3. tr=1.000 TxR=  531.
------------------------------
aluvo2w3m1 T=  0. az=  0. el=  1. tr=1.000 TxR= 3000.
aluvo2w3m1 T= 10. az=  0. el=  1. tr=0.450 TxR= 2383.
aluvo2w3m1 T= 20. az=  0. el=  1. tr=1.000 TxR= 1765.
aluvo2w3m1 T= 30. az=  0. el=  1. tr=1.000 TxR= 1148.
aluvo2w3m1 T= 40. az=  0. el=  3. tr=1.000 TxR=  531.
------------------------------
aluvo2w4m1 T=  0. az=  0. el=  1. tr=1.000 TxR= 3000.
aluvo2w4m1 T= 10. az=  0. el=  1. tr=1.000 TxR= 2383.
aluvo2w4m1 T= 20. az=  0. el=  1. tr=1.000 TxR= 1765.
aluvo2w4m1 T= 30. az=  0. el=  1. tr=1.000 TxR= 1148.
aluvo2w4m1 T= 40. az=  0. el=  3. tr=1.000 TxR=  531.
------------------------------
aluvo2w5m1 T=  0. az=  0. el=  1. tr=1.000 TxR= 3000.
aluvo2w5m1 T= 10. az=  0. el=  1. tr=0.350 TxR= 2383.
aluvo2w5m1 T= 20. az=  0. el=  1. tr=0.350 TxR= 1765.
aluvo2w5m1 T= 30. az=  0. el=  1. tr=0.300 TxR= 1148.
aluvo2w5m1 T= 40. az=  0. el=  3. tr=0.050 TxR=  531.
 Tar= 1 Bnd=uv Init Dwn Rng= 3000. Off-Rng= 1000.
------------------------------
aluvo2w1m1 T=  0. az= 18. el=  1. tr=1.000 TxR= 3000.
aluvo2w1m1 T= 10. az= 23. el=  1. tr=0.250 TxR= 2383.
aluvo2w1m1 T= 20. az= 30. el=  1. tr=1.000 TxR= 1765.
aluvo2w1m1 T= 30. az= 41. el=  1. tr=1.000 TxR= 1148.
aluvo2w1m1 T= 40. az= 62. el=  2. tr=1.000 TxR=  531.
------------------------------
aluvo2w2m1 T=  0. az= 18. el=  1. tr=1.000 TxR= 3000.
aluvo2w2m1 T= 10. az= 23. el=  1. tr=0.500 TxR= 2383.
aluvo2w2m1 T= 20. az= 30. el=  1. tr=1.000 TxR= 1765.
aluvo2w2m1 T= 30. az= 41. el=  1. tr=1.000 TxR= 1148.
aluvo2w2m1 T= 40. az= 62. el=  2. tr=1.000 TxR=  531.
------------------------------
aluvo2w3m1 T=  0. az= 18. el=  1. tr=1.000 TxR= 3000.
aluvo2w3m1 T= 10. az= 23. el=  1. tr=0.350 TxR= 2383.
aluvo2w3m1 T= 20. az= 30. el=  1. tr=1.000 TxR= 1765.
aluvo2w3m1 T= 30. az= 41. el=  1. tr=1.000 TxR= 1148.
aluvo2w3m1 T= 40. az= 62. el=  2. tr=1.000 TxR=  531.
------------------------------
aluvo2w4m1 T=  0. az= 18. el=  1. tr=1.000 TxR= 3000.
aluvo2w4m1 T= 10. az= 23. el=  1. tr=1.000 TxR= 2383.
aluvo2w4m1 T= 20. az= 30. el=  1. tr=1.000 TxR= 1765.
aluvo2w4m1 T= 30. az= 41. el=  1. tr=1.000 TxR= 1148.
aluvo2w4m1 T= 40. az= 62. el=  2. tr=0.150 TxR=  531.
------------------------------
aluvo2w5m1 T=  0. az= 18. el=  1. tr=1.000 TxR= 3000.
aluvo2w5m1 T= 10. az= 23. el=  1. tr=0.350 TxR= 2383.
aluvo2w5m1 T= 20. az= 30. el=  1. tr=1.000 TxR= 1765.
aluvo2w5m1 T= 30. az= 41. el=  1. tr=1.000 TxR= 1148.
aluvo2w5m1 T= 40. az= 62. el=  2. tr=1.000 TxR=  531.
```

```
Tar= 1 Bnd=uv Init Dwn Rng= 3000. Off-Rng= 2000.
--------------------------------
aluvo2w1m1 T= 0. az= 34. el= 0. tr=1.000 TxR= 3000.
aluvo2w1m1 T= 10. az= 40. el= 1. tr=0.200 TxR= 2383.
aluvo2w1m1 T= 20. az= 49. el= 1. tr=0.300 TxR= 1765.
aluvo2w1m1 T= 30. az= 60. el= 1. tr=0.450 TxR= 1148.
aluvo2w1m1 T= 40. az= 75. el= 1. tr=0.050 TxR= 531.
--------------------------------
aluvo2w2m1 T= 0. az= 34. el= 0. tr=1.000 TxR= 3000.
aluvo2w2m1 T= 10. az= 40. el= 1. tr=0.450 TxR= 2383.
aluvo2w2m1 T= 20. az= 49. el= 1. tr=1.000 TxR= 1765.
aluvo2w2m1 T= 30. az= 60. el= 1. tr=1.000 TxR= 1148.
aluvo2w2m1 T= 40. az= 75. el= 1. tr=1.000 TxR= 531.
--------------------------------
aluvo2w3m1 T= 0. az= 34. el= 0. tr=1.000 TxR= 3000.
aluvo2w3m1 T= 10. az= 40. el= 1. tr=0.250 TxR= 2383.
aluvo2w3m1 T= 20. az= 49. el= 1. tr=1.000 TxR= 1765.
aluvo2w3m1 T= 30. az= 60. el= 1. tr=1.000 TxR= 1148.
aluvo2w3m1 T= 40. az= 75. el= 1. tr=1.000 TxR= 531.
--------------------------------
aluvo2w4m1 T= 0. az= 34. el= 0. tr=1.000 TxR= 3000.
aluvo2w4m1 T= 10. az= 40. el= 1. tr=1.000 TxR= 2383.
aluvo2w4m1 T= 20. az= 49. el= 1. tr=0.350 TxR= 1765.
aluvo2w4m1 T= 30. az= 60. el= 1. tr=0.200 TxR= 1148.
aluvo2w4m1 T= 40. az= 75. el= 1. tr=1.000 TxR= 531.
--------------------------------
aluvo2w5m1 T= 0. az= 34. el= 0. tr=1.000 TxR= 3000.
aluvo2w5m1 T= 10. az= 40. el= 1. tr=1.000 TxR= 2383.
aluvo2w5m1 T= 20. az= 49. el= 1. tr=1.000 TxR= 1765.
aluvo2w5m1 T= 30. az= 60. el= 1. tr=1.000 TxR= 1148.
aluvo2w5m1 T= 40. az= 75. el= 1. tr=1.000 TxR= 531.
Tar= 1 Bnd=uv Init Dwn Rng= 3000. Off-Rng= 3000.
--------------------------------
aluvo2w1m1 T= 0. az= 45. el= 0. tr=1.000 TxR= 3000.
aluvo2w1m1 T= 10. az= 52. el= 0. tr=0.250 TxR= 2383.
aluvo2w1m1 T= 20. az= 60. el= 0. tr=0.100 TxR= 1765.
aluvo2w1m1 T= 30. az= 69. el= 1. tr=0.050 TxR= 1148.
aluvo2w1m1 T= 40. az= 80. el= 1. tr=0.050 TxR= 531.
--------------------------------
aluvo2w2m1 T= 0. az= 45. el= 0. tr=1.000 TxR= 3000.
aluvo2w2m1 T= 10. az= 52. el= 0. tr=0.400 TxR= 2383.
aluvo2w2m1 T= 20. az= 60. el= 0. tr=1.000 TxR= 1765.
aluvo2w2m1 T= 30. az= 69. el= 1. tr=1.000 TxR= 1148.
aluvo2w2m1 T= 40. az= 80. el= 1. tr=1.000 TxR= 531.
--------------------------------
aluvo2w3m1 T= 0. az= 45. el= 0. tr=1.000 TxR= 3000.
aluvo2w3m1 T= 10. az= 52. el= 0. tr=0.150 TxR= 2383.
aluvo2w3m1 T= 20. az= 60. el= 0. tr=1.000 TxR= 1765.
aluvo2w3m1 T= 30. az= 69. el= 1. tr=1.000 TxR= 1148.
aluvo2w3m1 T= 40. az= 80. el= 1. tr=1.000 TxR= 531.
--------------------------------
aluvo2w4m1 T= 0. az= 45. el= 0. tr=1.000 TxR= 3000.
aluvo2w4m1 T= 10. az= 52. el= 0. tr=0.400 TxR= 2383.
aluvo2w4m1 T= 20. az= 60. el= 0. tr=0.300 TxR= 1765.
aluvo2w4m1 T= 30. az= 69. el= 1. tr=0.400 TxR= 1148.
aluvo2w4m1 T= 40. az= 80. el= 1. tr=1.000 TxR= 531.
--------------------------------
aluvo2w5m1 T= 0. az= 45. el= 0. tr=1.000 TxR= 3000.
```

aluvo2w5m1 T= 10. az= 52. el= 0. tr=1.000 TxR= 2383.
aluvo2w5m1 T= 20. az= 60. el= 0. tr=1.000 TxR= 1765.
aluvo2w5m1 T= 30. az= 69. el= 1. tr=1.000 TxR= 1148.
aluvo2w5m1 T= 40. az= 80. el= 1. tr=1.000 TxR= 531.
Tar= 1 Bnd=uv Init Dwn Rng= 3000. Off-Rng= 4000.

---

aluvo2w1m1 T= 0. az= 53. el= 0. tr=1.000 TxR= 3000.
aluvo2w1m1 T= 10. az= 59. el= 0. tr=0.350 TxR= 2383.
aluvo2w1m1 T= 20. az= 66. el= 0. tr=0.100 TxR= 1765.
aluvo2w1m1 T= 30. az= 74. el= 0. tr=0.050 TxR= 1148.
aluvo2w1m1 T= 40. az= 82. el= 0. tr=0.100 TxR= 531.

---

aluvo2w2m1 T= 0. az= 53. el= 0. tr=1.000 TxR= 3000.
aluvo2w2m1 T= 10. az= 59. el= 0. tr=0.350 TxR= 2383.
aluvo2w2m1 T= 20. az= 66. el= 0. tr=1.000 TxR= 1765.
aluvo2w2m1 T= 30. az= 74. el= 0. tr=1.000 TxR= 1148.
aluvo2w2m1 T= 40. az= 82. el= 0. tr=1.000 TxR= 531.

---

aluvo2w3m1 T= 0. az= 53. el= 0. tr=1.000 TxR= 3000.
aluvo2w3m1 T= 10. az= 59. el= 0. tr=0.150 TxR= 2383.
aluvo2w3m1 T= 20. az= 66. el= 0. tr=1.000 TxR= 1765.
aluvo2w3m1 T= 30. az= 74. el= 0. tr=1.000 TxR= 1148.
aluvo2w3m1 T= 40. az= 82. el= 0. tr=1.000 TxR= 531.

---

aluvo2w4m1 T= 0. az= 53. el= 0. tr=1.000 TxR= 3000.
aluvo2w4m1 T= 10. az= 59. el= 0. tr=0.400 TxR= 2383.
aluvo2w4m1 T= 20. az= 66. el= 0. tr=0.250 TxR= 1765.
aluvo2w4m1 T= 30. az= 74. el= 0. tr=1.000 TxR= 1148.
aluvo2w4m1 T= 40. az= 82. el= 0. tr=1.000 TxR= 531.

---

aluvo2w5m1 T= 0. az= 53. el= 0. tr=1.000 TxR= 3000.
aluvo2w5m1 T= 10. az= 59. el= 0. tr=1.000 TxR= 2383.
aluvo2w5m1 T= 20. az= 66. el= 0. tr=1.000 TxR= 1765.
aluvo2w5m1 T= 30. az= 74. el= 0. tr=1.000 TxR= 1148.
aluvo2w5m1 T= 40. az= 82. el= 0. tr=1.000 TxR= 531.
Tar= 1 Bnd=uv Init Dwn Rng= 3000. Off-Rng= 5000.

---

aluvo2w1m1 T= 0. az= 59. el= 0. tr=1.000 TxR= 3000.
aluvo2w1m1 T= 10. az= 65. el= 0. tr=0.350 TxR= 2383.
aluvo2w1m1 T= 20. az= 71. el= 0. tr=0.150 TxR= 1765.
aluvo2w1m1 T= 30. az= 77. el= 0. tr=0.100 TxR= 1148.
aluvo2w1m1 T= 40. az= 84. el= 0. tr=0.100 TxR= 531.

---

aluvo2w2m1 T= 0. az= 59. el= 0. tr=1.000 TxR= 3000.
aluvo2w2m1 T= 10. az= 65. el= 0. tr=0.350 TxR= 2383.
aluvo2w2m1 T= 20. az= 71. el= 0. tr=1.000 TxR= 1765.
aluvo2w2m1 T= 30. az= 77. el= 0. tr=1.000 TxR= 1148.
aluvo2w2m1 T= 40. az= 84. el= 0. tr=1.000 TxR= 531.

---

aluvo2w3m1 T= 0. az= 59. el= 0. tr=1.000 TxR= 3000.
aluvo2w3m1 T= 10. az= 65. el= 0. tr=0.150 TxR= 2383.
aluvo2w3m1 T= 20. az= 71. el= 0. tr=1.000 TxR= 1765.
aluvo2w3m1 T= 30. az= 77. el= 0. tr=1.000 TxR= 1148.
aluvo2w3m1 T= 40. az= 84. el= 0. tr=1.000 TxR= 531.

---

aluvo2w4m1 T= 0. az= 59. el= 0. tr=1.000 TxR= 3000.
aluvo2w4m1 T= 10. az= 65. el= 0. tr=0.350 TxR= 2383.
aluvo2w4m1 T= 20. az= 71. el= 0. tr=0.200 TxR= 1765.

aluvo2w4m1 T= 30. az= 77. el= 0. tr=1.000 TxR= 1148.
aluvo2w4m1 T= 40. az= 84. el= 0. tr=1.000 TxR= 531.

---

aluvo2w5m1 T= 0. az= 59. el= 0. tr=1.000 TxR= 3000.
aluvo2w5m1 T= 10. az= 65. el= 0. tr=1.000 TxR= 2383.
aluvo2w5m1 T= 20. az= 71. el= 0. tr=1.000 TxR= 1765.
aluvo2w5m1 T= 30. az= 77. el= 0. tr=1.000 TxR= 1148.
aluvo2w5m1 T= 40. az= 84. el= 0. tr=1.000 TxR= 531.

APPENDIX B

OBSCURANTS MODELING

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OBSCURANTS MODELING

The COMBIC model was run for the M76 IR and L8A1 RP smoke grenades (UV and IR spectral bands, five wind directions, and five meteorological conditions) and vehicular dust obscurant (UV and IR spectral bands, five wind directions, five meteorological conditions, two vehicle speeds, and two vehicle separations). The scenarios are depicted in Figure B-1 for the self-defensive grenades and Figure B-2 for vehicular dust obscurant. The specific conditions modeled are given next.

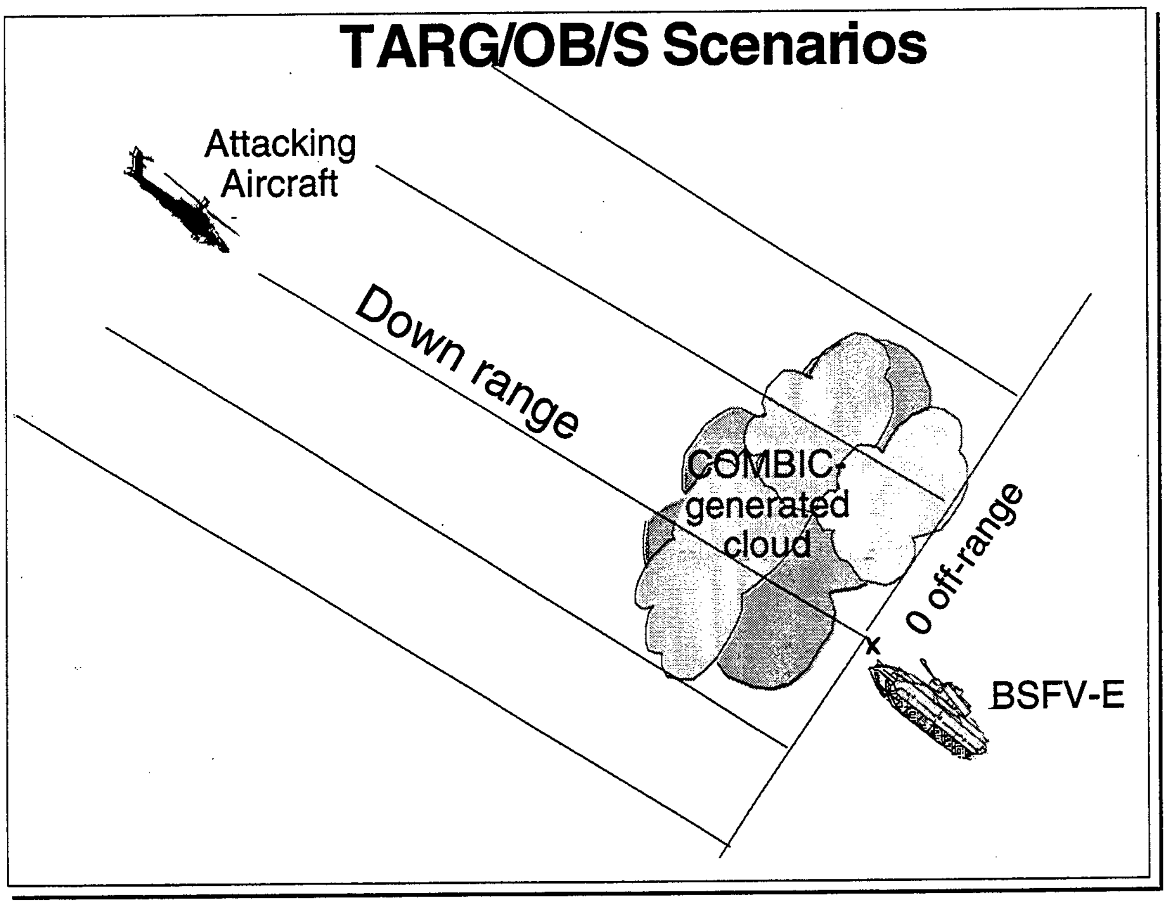

Figure B-1. COMBIC Scenario for Self-Defensive Grenade Smoke.

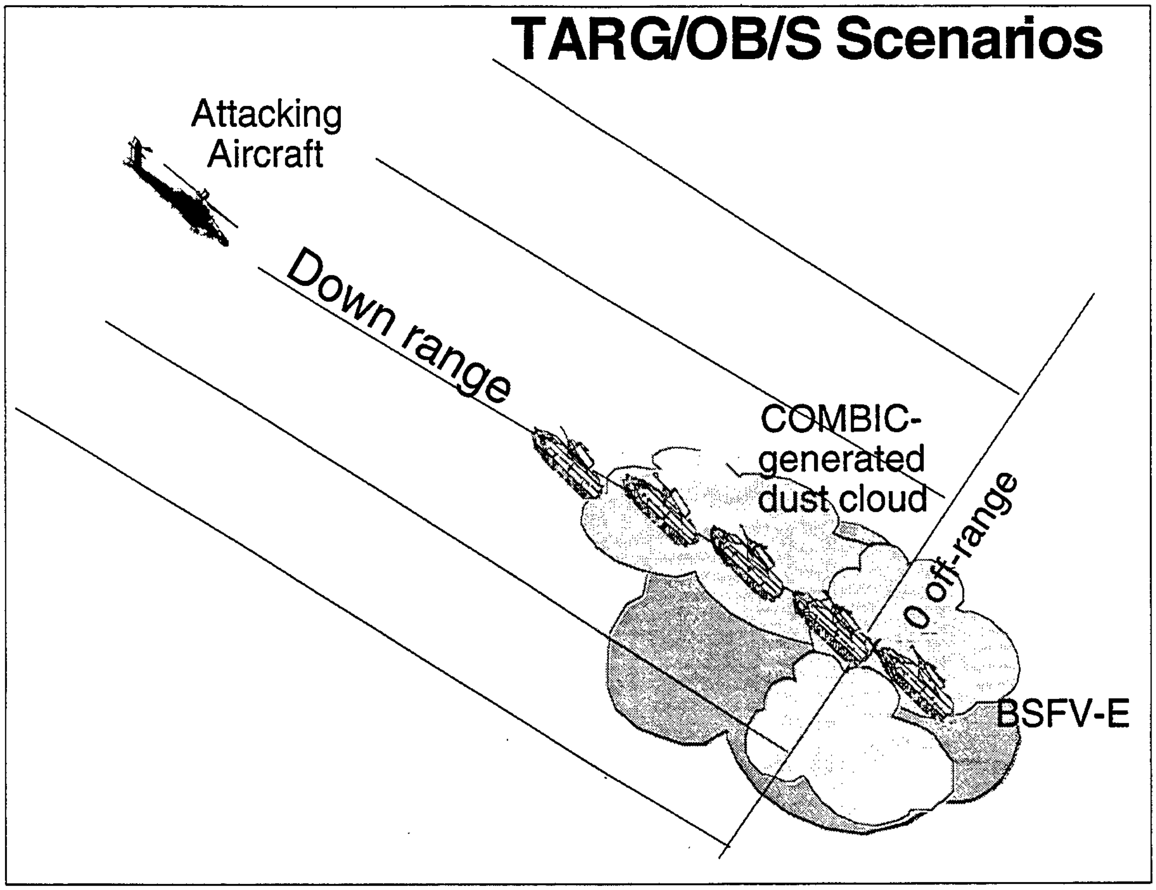

Figure B-2. COMBIC Scenario for Vehicular Dust.

Obscurants Conditions Modeled for Example Study.

Smoke/obscuration mass extinction coefficients used in the study are shown in Table B-1.

Table B-1. Mass Extinction Coefficients (m^2/g) for Obscurants Used in the Study

Obscurant	Mass Extinction Coefficients (m^2/g) in the Stinger Seeker Spectral Bands	
	UV 0.20 to 0.40 microns	Mid-IR 3.0 to 5.0 microns
Red Phosphorus (L8A1 smoke)	3.23	0.41
Brass (M76 IR smoke)	1.0	1.0
Vehicular dust	0.32	0.27

Wind direction conditions

The wind directions modeled were cross (right to left), head, quartering (moves at approximately 45° to/from the forward line of own troops [FLOT], reverse quartering (opposite direction of quartering), and tail. The wind directions are graphically shown in Figure B-3.

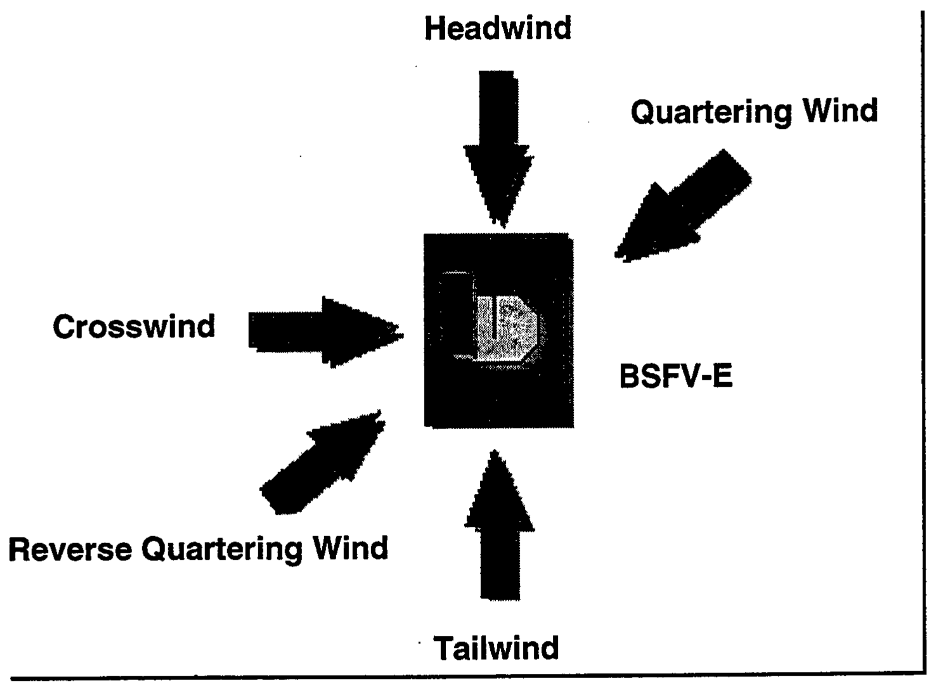

Figure B-3. Wind Direction Definitions.

Meteorological Conditions

Smoke released during certain times of the day, such as early morning hours when the atmosphere is quiescent, is significantly different than smoke released on a hot sunny afternoon when the atmosphere is unstable. Atmospheric stability is categorized into three temperature gradients: inversion (stable), adiabatic (neutral), and lapse (unstable). Temperature gradient is an expression of the difference in air temperature and ground temperature. COMBIC was run for the meteorological condition values listed in Table B-2.

Five-Linebacker Column

These were 50-meter separations between vehicles moving at 20 km/hr, 50-meter separations between vehicles moving at 32 km/hr, 100-meter separations between vehicles moving at 20 km/hr, and 100-meter separations between vehicles moving at 32 km/hr.

UV and IR Spectrum Conditions

Transmittance was calculated for the 3- to 5-µm mid-IR and the UV electromagnetic energy bands. COMBIC normally does not include the UV band, so a Mie scattering model was used to produce the mass extinction coefficients for this band.

Field of View (FOV) Conditions

The horizontal (azimuth) axis was -90° to +90° and the vertical (elevation) axis was 0° to 57° (maximum elevation angle of the SVML). COMBIC scenarios establish Xo, Yo, Zo as the coordinates of seeker. Each plot consists of a two-dimensional (azimuth and elevation) view of the transmission level along the LOS that the seeker sees when looking through the cloud located 1000 meters down range. For the vehicular dust trials, Zo changes with time because the observer is moving in the Z direction (down range) at 20 and 32 km/hr.

Table B-2. Meteorological Conditions Used in COMBIC Scenarios

	met- 1*	met- 2	met- 3	met- 4	met- 5
Wind speed (m/sec)	2.6	2.6	2.6	5.1	7.7
Relative humidity (%)	90	90	90	90	90
Air temperature (°K)	297.5	297.5	297.5	297.5	297.5
Surface roughness (m)	.1	.1	.1	.1	.1
Pasquill category**	F, 5.6 (stable)	B, 1.6 (unstable)	D, 3.6 (neutral)	D, 3.6 (neutral)	D, 3.6 (neutral)
Air pressure (millibars)	1000	1000	1000	1000	1000

* met- 1 (stable Pasquill category) was used in this study.

** Pasquill category is a measure of atmospheric stability based upon solar loading, wind speed, and temperature.

Vehicular dust and moving smoke sources such as generators are included. However, COMBIC does not model accelerations and changes in direction by moving sources. All moving sources are modeled as moving in a straight line at a constant velocity. Changes in direction by moving sources can be simulated by COMBIC by stopping the vehicle and starting it again moving toward a new direction.

COMBIC Modifications Made for the Example Study

EOSAEL 92 COMBIC can show output in two ways. The first method creates parallel LOSs surrounding a central LOS specified by the inputs. All the LOSs originate on a plane and end on a plane parallel to the first plane. All LOSs are of equal length. COMBIC provides an orthographic representation of the obscurant cloud. The second method creates LOSs surrounding a central LOS specified by the user. In the perspective picture, all the LOSs originate with the specified observer. The LOSs end normally on a plane and are of various lengths. This provides a perspective representation of the obscurant cloud. As an example, your eye gives you a perspective representation of the visual world. These two types of viewing the battlefield can yield different values on the obscuration levels. This report uses a modified perspective aspect, since we are interested in the ability of the Stinger missile on the Linebacker to acquire the target. The observer location is placed at the location of the Linebacker. COMBIC was modified to allow the observer coordinates to be the same as for the Bradley and the missile seeker. Previously, the observer was not allowed to move. Now, the observer can move in a constant direction with constant velocity to match the coordinates of the Bradley and missile sensors. The resultant output will be what the sensors sees. The width and height of the window used to define the printer plot are defined by the user. The corresponding number of characters across the printed page, as many as 100 generally, and the lines down the printed page, which have no set limit, are also input. These define the number of meters per character or, in other words, the resolution for the resultant listing.

COMBIC Assumptions and Limitations

COMBIC uses a simple atmospheric boundary layer model. The wind field direction and vertical wind speed profile are uniform everywhere in the scenario. In the real world, wind fields and diffusion rates are determined by the effects of complex terrain and surface properties. COMBIC is a "flat terrain model" which allows only for a uniform boundary layer wind field that is assumed to apply over the entire geographic region. Smoke diffusion is a stochastic atmospheric process. Natural atmospheric turbulence will modify the smoke cloud in a random fashion. This produces thick and thin screening spots, which are most evident near smoke sources. COMBIC is a deterministic model and its output is meant to show the average effects of a random process. Variations in the atmosphere make the smoke less effective if the target can be acquired through momentarily thin spots in the cloud. COMBIC computes transmittance using "Beer-Lambert" law equation which includes the results of single scattering out of the path and absorption along the path. COMBIC does not compute multiple scattering contribution to the energy received by the seeker. The effect of radiance along the LOS should also be considered. The path radiance contributions are the subject of other models that examine the effects of emissive sources and of single scattering of the ambient radiation into the LOS.

Vehicular dust and moving smoke sources such as generators are included. However, COMBIC does not model accelerations and changes in direction by moving sources. All moving sources are modeled as moving in a straight line at a constant velocity. Changes in direction by moving sources can be simulated by COMBIC by stopping the vehicle and starting COMBIC models extinction and not path radiance. Extinction is composed of a scattering of light energy.

Transmittance is still the key component in these more complex models and is important because it quantifies when a received signal will be below some operational threshold of an EO device. However, transmittance is not the only quantity that determines the energy that is detected. Just as extinction removes energy along a path, multiple scattering can return some of that energy. The Beers-Lambert law equation includes the results of single scattering out of the path and absorption along the path. Once the energy is scattered from the path, it is gone. Some probability exists, however, that a fraction of the energy scatters more than once. Some of this energy, not itself absorbed by the aerosol, may return close to the optical path and scatter again in approximately the original direction of the beam. COMBIC does not compute this multiple scattering contribution to the energy received by finite area collection optics.

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REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	August 1998	Final

4. TITLE AND SUBTITLE

Methodology for the Analysis of Obscurant Attenuation Effects on Seeker Target Acquisition Performance Using Modeling and Simulation

5. FUNDING NUMBERS

PR: 6LC2T1

6. AUTHOR(S)

Andrese, J.A. (ARL)

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

U.S. Army Research Laboratory
Survivability/Lethality Analysis Directorate
Aberdeen Proving Ground, MD 21010-5423

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

U.S. Army Research Laboratory
Survivability/Lethality Analysis Directorate
Aberdeen Proving Ground, MD 21010-5423

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

ARL-TR-1608

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT

Approved for public release; distribution is unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

A methodology was developed which uses modeling and simulation to obtain data for analyzing smoke/obscurant attenuation effects on sensor/seeker target acquisition performance. A computer routine written in Formula Translator (FORTRAN) 77 code integrates smoke/obscurant clouds generated by the combined obscuration model for battlefield-induced contaminants (COMBIC) with seeker performance from a system hardware-in-the-loop simulation. The methodology can be applied to other system models and simulations. The computer routine calculates the azimuth and elevation angular position of the line of sight (LOS) between the seeker and an incoming threat aircraft, determines the transmission along the LOS between the seeker and aircraft, and obtains the smoke/obscurant-attenuated seeker target acquisition range from the system simulation. Output consists of seeker target acquisition range contours as functions of target down-range and off-range positions and smoke/obscurant conditions. Seeker performance analysis consists of the extent of degradation of maximum acquisition range, statistical comparisons of the percent frontal area target acquisition coverage figure of merit as a function of smoke/obscurant conditions, and the ability to meet maximum acquisition range requirements at specified optical depths. The Bradley Linebacker Stinger target acquisition performance in battlefield smoke/obscurants is included as an example of the methodology usage.

14. SUBJECT TERMS

attenuation effects	obscurant	sensor	Stinger seeker
Bradley linebacker	optical depth	simulations	target acquisition
models	seeker	smoke	transmission

15. NUMBER OF PAGES

60

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	